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Kirkaldy, John
Knudson, Gunnar
Korshicoff, Nicolas, General, Russian Imperial Navy

Labrano, F., Captain, Italian Royal Navy
Lagane, Amable
Lagerwall, J. M., Captain, Royal Swedish Navy
Lamont, Henry
Lautrup, Christian
Laws, George A.
Lee, John D.
Lewes, Vivian B.
Likhatchof, J., Vice-Admiral, Imperial Russian Navy
Linnard, Joseph Hamilton
Lister, W. N., Lieut., R.N.R.
Little, Henry W.
Littleboy, C. W.
Ljungstedt, A. G. A., Captain, Swedish Royal Navy
Long, A. E.
Long, Samuel, Captain, R.N.
Lyster, G. Fosbery
Lund, William
Lüning, J. G.

MacDougall, Dugald
MacIlwaine, Captain George S.
MacIver, C.
MacIver, H.
Mackenzie, James
Mackenzie, Landseer
Martin, Edwin
Martin, Sir Wm. F., Bart., K.C.B., Admiral
McDonnell, Alexander
McGregor, J.
McHardy, Wallace Bruce, Commander, R.N.
McIlwraith, Andrew
Medhurst, John T.
Milburn, J. D.
Milburn, William, jun.
Miller, Gordon
Milne, Sir Alexander, Bart., G.C.B., Admiral of the Fleet (Vice-President)
Moore, William W.

Neal, William George
Neilson, John
Neilson, Walter M., Colonel
Newman, A. R.
Nicolson, Sir Frederick W. E., Bart., C.B., Admiral (Vice-President)
Noel, G. H., Captain, R.N. (Assoc. Mem. Council)
Northbrook, The Right Hon. the Earl, G.C.S.I. (Vice-President)
Norton, Harold Percival

Orlando, Paolo

Palmer, William
Pearse, Mountjoy
Perkins, James
Pile, Charles H.
Poretchkin, Theodore, Lieut., I.R.N.
Potter, John
Pover, W. T.
Price, Arthur, R.N.

Ramsden, Sir James, Kt. (Vice-President)
Ratliffe, G.
Ravensworth, The Right Hon. the Earl of (President)
Rawson, Robert, Hon. Mem. Manchester Literary and Philosophical Society
Rendel, Hamilton Owen
Rennie, J. K.
Rice, J. M., United States Navy
Riley, James
Robinson, M. H.
Robinson, Sir R. Spencer, K.C.B., F.R.S., Admiral (Vice-President)
Rose, Captain J. B.
Rothe, H. P., Commodore, Danish Royal Navy
Rothery, H. C., Q.C.
Rowan, David
Rowley, Charles J., Captain, R.N.
Rundle, Cubitt S.

Samuelson, Sir Bernhard, Bart., C.B., M.P.
Sandham, Henry
Sandison, Magnus
Sandstrom, Theodore C. A., Com., Royal Swedish Navy
Satrustegui, Don Patricia de
Saunders, James Ebenezer
Schmeman, Alexander
Schüler, F.
Schunk, Theodore
Scott, George J.
Serena, Arthur
Shankland, Robert
Smith, G. Fereday
Smith, John
Smith, The Right Hon. W. H., M.P. (Vice-President)
Smyth-Pigott, J. H.
Spence, James
Spencer, John W.
Stothert, G. K.

Stuart, Milton
Stumore, Frederick
Sudeley, The Right Hon. Lord
Swinburne, Thos. A., Captain, R.N.
Symonds, Thos. E., Captain, R.N.

Tatham, Hollings
Taylor, J. M. H.
Temperley, Joseph
Thayer, Ignatius E.
Thomson, Andrew
Thurston, Robert H., Professor
Tindall, William H. (Vice-President)
Tough, R. T.
Tryon, George, Rear-Admiral, C.B., R.N.

Vavasseux, Josiah
Vaz, J. M. P. da F., Captain, Royal Italian Navy

Waddilove, Charles L. D., Vice-Admiral, R.N.
Watson, George
Watson, Henry James
Watson, W.
Watson, William
Watts, Edmund H.
Webb, F. W.
Webb, J. Beavor
Westmacott, Percy G. B.
Wheatley, William Coe
Wheeler, Joseph, jun.
Whyham, Maurice
Williams, Samuel
Williamson, J.
Williamson, R. H.
Wilmot, S. Eardley, Captain, R.N.
Wingfield, G. J., Lieut., R.N.
Wise, William Lloyd
Woodall, J. W.
Woodward, Joseph J.
Woolfe, J. S.

Ziffer, J. H.

OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, viz., Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

13. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum.*

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of

Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

30. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely:—

1*st.* A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2*nd.* Lists for the election of the Ordinary Members and Associate Members of Council. This List shall contain the names of the existing Ordinary Members of Council and Associate Members of Council, and at least *six* new names of Members, and at least *two* of Associates of the Institution.

31. No addition shall be made to the total number of Ordinary Members of the Council until, by death or resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

32. At the date of issuing the Syllabus of the Annual General Meetings in each year, the complete Lists proposed by the Council for the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the existing Ordinary Members of Council at the time of the preparation of the Balloting List, together with six new names of Members of the Institution (or, if the number shall have been reduced below twenty-four, then so many new names as shall be needed to bring the number up to thirty), and the whole of these names shall be printed in alphabetical order. Secondly, the names of the existing Associate Members of Council at the time of the preparation of the Balloting List, together with two new names of Associates of the Institution (or, if the number shall have been reduced below eight, then so many new names as shall be needed to bring the number up to ten), and these names also shall be printed in alphabetical order. From these Lists the new Council shall be elected. Every Member shall be at liberty to strike out any name on the Lists, but he must strike

out *six* names from the List of Members of Council, and *two* names from the List of Associate Members of Council.

33. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to strike out any names on that List; but he *must* reduce the number by striking out *two* names from the List of Associate Members of Council.

34. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

35. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall next nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council; and

(5) The Scrutineers, assisted by the Secretary and his clerks, shall receive the Ballot Papers which may have reached him, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

36. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

DESIGNATION OF MEMBERS AND ASSOCIATES.

37. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

38. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his

claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

39. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

40. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

41. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

42. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

43. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

44. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

45. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

46. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of Council why such subscriptions were not previously paid.

47. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

48. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

49. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall by him be laid before the Council for consideration. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

50. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

51. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

52. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

53. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

54. Members and Associates are particularly requested to communicate to the Secretary any change of address.

PROCEEDINGS AT LIVERPOOL.

INSTITUTION OF NAVAL ARCHITECTS.

JULY 27, 28, 29 & 30, 1886.

PRELIMINARY PROCEEDINGS.

27th July, 1886.

Sir David Radcliffe (Mayor of Liverpool, Chairman of Reception Committee): I have very great pleasure in bidding you, my Lord and Members of the Institution of Naval Architects, a hearty welcome to the City of Liverpool, and I sincerely hope you will enjoy yourselves whilst you are staying with us here. There are objects in the City and in connection with it which I am sure will afford you very great pleasure in looking upon. We have also, as you are aware, an Exhibition in the City, and that too I believe is replete with models of vessels shewing your great skill in the designing and planning of ships in connection with this and other great commercial ports. I will call on the Earl of Ravensworth to take the chair and proceed with the business for which we have met.

The President: Sir David Radcliffe and Gentlemen, I rise on behalf of the Institution with which I have the honour to be connected to tender to you, Sir David Radcliffe, Mayor of this great City, to the Members of the Reception Committee, and to the people of Liverpool generally, I fear in most inadequate phrases, our most grateful and sincere acknowledgments and thanks for the great honour you have conferred upon the Institution with which I am connected, for your kind invitation and your very kind reception of us this day. Gentlemen, I shall not detain you at any length because time is valuable; we have a great deal to see and a great deal to hear, and I think we all know pretty well that trains and tides do not wait for anybody, therefore I shall endeavour to confine the few observations that it is my duty to make to you within the shortest possible compass. Gentlemen, this is the second time only that this Institution has held what I may call a Summer Meeting as distinguished from our Spring Meetings, which are regularly held in the Spring of every year in London, and when the first proposal was made, or was suggested, that Liverpool should be chosen I confess to you I hailed the proposition with very great cordiality. I will go further, Gentlemen, than that, and will tell you that I ventured upon doing that which is under the ordinary circumstances of life a very dangerous thing to do: I prophesied that it would be a successful Meeting. Now, I founded that prediction upon a pretty good basis, namely, personal experience. I have had the honour of knowing many friends in Liverpool for many years. My father before me had the honour and privilege of representing this great constituency for several years, and I never shall forget, as long as I live, his sense of gratitude to that constituency. I have on several occasions largely shared in that experience, and I have myself tested the kindness and generosity of the people of Liverpool on more than one occasion. Now, Gentlemen, I need not tell you that these are reminiscences of a most agreeable kind which no lapse of time can efface, but which my feeble words can only very inadequately express. But there are other reasons besides personal reasons why I think it was clear to the Council and Members of the Institution generally that Liverpool was of all places probably the most fitting for the meeting of the scientific body with which I am connected. Liverpool I have heard not inappropriately described as the second City of the Empire; Liverpool is undoubtedly the chief port of export and import for the United Kingdom, and possibly in passing I may venture and be permitted to express a very fervent hope and belief that Liverpool is destined for many years to come to hold that position. Liverpool is the point of departure for those magnificent fleets of Atlantic steamers which are alike the pride, the admiration, and the envy of the

world; Liverpool, last but not least, is the connecting link between England, the United Kingdom, and that vast, that powerful, that friendly nation—and I place great stress upon the word "friendly"—on the other side of the Atlantic; it is the connecting link between these two great countries, and I use the word "friendly" from a firm conviction and belief that almost every well-minded man on either side of the Atlantic believes that friendship to be based upon the firm foundation of mutual respect and mutual esteem, and I trust and hope and believe that the great aim and object, or at any rate a chief aim and object, at all times on the part of leading statesmen in this country, will be to merit and to maintain that esteem and friendship. Well, therefore, Gentlemen, undoubtedly Liverpool of all places perhaps in this kingdom is the most suitable for the meeting of a scientific body such as I have the honour to represent here to-day. But the time is peculiarly suitable, because, as Sir Edward Radcliffe has reminded you, we shall have the opportunity of visiting that Exhibition of which I have only heard by rumour, but which I am led to believe and hope is a very successful Exhibition. We shall be able to trace in the magnificent collection of ships' models, there exhibited, that mighty progress in naval architecture which is certainly one of the wonders of this age; we shall be able to trace that progress from the days of the wooden steamers to the iron steamers and down to the steel steamers of the present time. But, Gentlemen, I think you will agree with me that progress is not at all confined to the naval architect, it is certainly equalled if not exceeded by another sister department of the same science, I mean by the efforts and the success of the marine engineer. We shall be able to trace probably the progress of marine engineering from the old paddle wheel down to the screw, and the twin screw now so commonly used; we shall see the advance in engineering science from the old, the very costly, and certainly the uneconomical engine down to the triple-expansive engine which is now of such general use in the Royal and Commercial Navies of this country; and I am happy to observe that we shall have a Paper which is in most able hands: knowing the author of the Paper, I am sure he will do ample justice to the great subject of Atlantic Steamers. We shall also on the same day hear a Paper read "On the Progress and Development of Marine Engineering." We shall also have on this very day a Paper upon a subject that cannot fail to be of the greatest interest, and I may say advantage, from the Engineer of your great Docks in this City. That Paper, I believe, will be followed up by a visit to those mighty works which under the genius and guardian care of the Chief Engineer have been created and matured; and it will be of the greatest possible interest I am sure to every Member of our Institution to see those marvellous works *in extenso*, as I hope we shall have the opportunity of doing. By the kindness of some friends of my own and some of your leading citizens we shall have the pleasure of visiting some of these great Atlantic Liners. We shall have an opportunity, by the kindness of my friend Mr. Ismay, of seeing one of the White Star Line, and we have also received a cordial invitation from Mr. Inman, which I am afraid that time will not enable us to avail ourselves of, to visit one of his magnificent steamers; and I also hope that we shall have the pleasure of seeing one of the largest and finest vessels of the Cunard Line, I mean the *Etruria*.

Well, Gentlemen, I only trust, and I venture to believe, that the advantages of this visit, great as they are, will not be altogether one-sided. I hope that the advantages will be reciprocal, and that the visit of the learned body with which I am associated, although not from any merit whatever of my own, will be of some advantage to this great community. I cannot help hoping that friendships may be formed, that ideas may be disseminated and reciprocated upon leading subjects connected with steam navigation and ship construction, which may be of advantage to many, and that a comparison of ideas as

to experiment and science on the one hand, and practical knowledge and experience on the other, may be of advantage to both the inhabitants of this great City and also to the Institution. You have nothing to do, Gentlemen, but to look carefully through the programme which has been prepared for us, and to study that programme carefully, to see the objects of interest which, under the best, ablest, and most competent guides, we shall be able to visit, and to see that really nothing has been left undone that could have been done for our comfort and instruction and our amusement during our stay here. I will not detain you further, Gentlemen. I have only been able most inadequately to express what I personally, and what I know every Member of my Council and the Institution, feel in coming here—namely, the utmost gratitude to all of you for the kindness with which you have invited us here, and the cordiality with which you have received us. Gentlemen, I return you my most hearty thanks, and thank you for the patience with which you have listened to me.

Gentlemen, I must now proceed with some formal business. It is my duty as President on this occasion to propose to you an alteration in our Rules. That sounds rather alarming, but I think I can in two words explain to you why it is that the Council have come to the unanimous conclusion. It is Rule 39, and my simple proposition is this: in line seven to strike out all the words after the word "application" down to the word "Council," the words being "and such four-fifths constitute a majority of the professional Members of the Council." I will tell you exactly how that Rule works, and then leave it to your good judgment to see whether the proposition I make is not one that ought to meet with your approval. There are at present thirty-four professional Vice-Presidents and Members of the Council of this Institution. By this Rule a new Member must receive an absolute majority of the votes of those professional Members in order to be elected, that is to say he must at least have eighteen votes. Now many Members of Council do not vote at all, and it is very often extremely difficult to secure the minimum eighteen votes even when all the received votes are in his favour; for example—a candidate who receives seventeen votes in his favour and not one vote against him would not be elected under this Rule. If twenty votes were received and there were only three against the candidate he would not be elected. Therefore, Gentlemen, I think you will see at once it is a rule that militates against the admission of many men who otherwise are unexceptionable candidates, and whom it would be a great advantage to this Institution to enrol amongst its Members. Therefore, with this explanation, which I have made as plain as I could, and I think nobody could misunderstand it, I propose the omission in line seven of Rule 39 of the words "And such four-fifths constitute a majority of the professional Members of the Council." As time is valuable I will at once ask those in favour of the omission of those words, which have been unanimously accepted by the Council and recommended to be laid before you at a General Meeting, to hold up their hands.

[The Resolution, having been put to the Meeting, was carried unanimously.]

The President: I will now call upon Mr. Martell to read his Paper upon what is, to me certainly, a most interesting subject.

ON THE CARRIAGE OF PETROLEUM IN BULK ON OVER-SEA VOYAGES.

By B. Martell, Esq., Member of Council.

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Notwithstanding the fact that thirty years have now elapsed since the discovery of petroleum in America, and that its production has grown so rapidly as to cause it to occupy the fourth place on the list of exports from that country, the efforts of British shipowners have been up to the present time but little exercised in competing with foreign shipowners for the over-sea carrying trade of that commodity. The reasons for this indifference may, perhaps, not be difficult to trace. It could not have been in consequence of the limited extent of the trade, as we find that this has been constantly increasing, and that last year no less than 1,531,000 tons were exported from the United States alone, representing in the aggregate a freight value of over a million and a half sterling, while of this amount about 227,000 tons were brought to the United Kingdom. The real cause is probably to be found in the nature of the cargo itself; in the danger arising from its inflammable properties; and from the difficulty of eradicating the smell of the oil, which thus renders a vessel unfit for the carriage of general cargoes after its discharge. The latter consideration has led to the carriage of petroleum—particularly as regards wooden vessels, which are more permanently affected—becoming almost a distinct branch of trade. Further, while the general cargo-carrying trade of the world was fairly remunerative, the same necessity did not exist—in view of the great proportion of tonnage held by British shipowners—for engaging in a trade to which the objections alluded to attached. The consequence has been that foreign owners of wooden sailing vessels have practically possessed a monopoly of over-sea petroleum carrying.

The time, however, has arrived when British shipowners can no longer afford to ignore any branch of the carrying trade in which they can successfully compete, and it is thought the trade in question is of sufficient importance to call forth their well-known enterprise and energy. The apparently unlimited supply of petroleum which, in addition to that from the American wells, exists in the Baku district of the Caucasus, and which has been so prominently brought under the notice of the public in the interesting work of Mr. C. Marvin, entitled "The Region of the Eternal Fire," together with other recently discovered

supplies, would seem to show that, even if vessels are specially built for the purpose of carrying oil, no fear need arise in the minds of shipowners of the exhaustion of the supply.

The consideration to which I wish first to direct your attention is as to the economic aspect of the question of the carriage of petroleum on board ship for over-sea voyages. Nearly the whole of the petroleum shipped in America for British and European ports is carried at present either in barrels, or in tin boxes cased with wood. An ordinary barrel is 33 inches long and 25 inches in diameter at the middle, and weighs when full about 400 lbs. Such a cask holds about 42 imperial gallons, and its own weight is 64 lbs., or about one-fifth of that of the oil it contains. It is estimated that in stowing this cargo, three and a-half casks take up on the average a ton of 50 cubic feet, and it would, therefore, occupy 80 cubic feet per ton deadweight. But as most modern three-deck steamers, fitted with water ballast in the holds in the usual way, cannot be brought to their load draught with cargoes occupying more than about 50 cubic feet to the ton, it will be seen that a great loss of cargo-carrying power is sustained by shipping petroleum in such vessels in casks, through the fact that the whole of the available cargo space is occupied long before the vessel is brought down to her proper load draught.

Thus, by way of illustration, if a steam vessel that could carry 2,000 tons of cargo, occupying as a limit 50 cubic feet to the ton, were filled with petroleum in barrels, she would carry only 1,250 tons dead weight. Of this quantity, moreover, about 16 per cent. would represent the tare of the casks, thus reducing the actual amount of petroleum to 1,050 tons. From this again it is usual to deduct two per cent. for leakage, and if such an amount of leakage does occur in practice, the nett weight of oil usefully carried becomes reduced to about 1,030 tons, as against 2,000 tons of ordinary deadweight cargo. As the specific gravity of American kerosine is ·80, and that of Russian about ·82, it would occupy in bulk less than 50 cubic feet to the ton, the average volume being about 45 cubic feet, and, therefore, no difficulty in carrying a full cargo would arise. The special fittings requisite for such a method, including the pumps, would, of course, have the effect of greatly reducing the above difference of 970 tons against the barrels, but there would be still left a large margin in favour of the carriage of oil in bulk.

But the advantage due to a difference in carrying power, great though it be, is not the only consideration. Another important economic question which arises in connection with the barrel system is that of the cost of the barrels themselves. Their value in the United States is stated to be from 4s. 6d. to 5s. 6d. each, and, with the exception of the few that are taken back to America, they are sold in London when empty for from 3s. 6d. to 4s. each. The depreciation of from 1s. to 1s. 6d. in the value of the barrel, which amounts to as much as from £350 to £475 for one voyage in the case quoted above, is saved under the bulk system. At present it has to be borne by the consumer of the oil, and, by enhancing the cost, has an effect in restricting the use of the commodity which would disappear if the employment of casks were discontinued.

The loss is even greater in respect of the cases in which a large proportion of the oil is carried. The raw tin is bought in Wales, shipped to the United States, and there made into boxes protected by a wood casing. The cost of these cases is nearly equal to that of the oil they contain. On their arrival at the port of discharge they have, when emptied of their contents, no value whatever, and the full cost of their manufacture has to be charged upon the oil, at the same time some advantage is gained in carrying power, as the cases stow more closely than barrels.

The degree of rapidity with which the cargo can be loaded or discharged under each of the systems is also of great economic importance. One steamer specially designed to carry oil in bulk, and which can take on board 1,700 tons of that commodity, can load or unload in five or six hours with suitable facilities for discharge; with a cargo of barrels the operation would take nearly as many days.

Whether, therefore, regard be had to the amount of cargo carried, to the loss incurred in respect of the depreciation in the value of the barrel, or to the rapidity with which loading or unloading takes place, the balance of economic advantage is clearly and overwhelmingly in favour of the carriage of petroleum in bulk.

These considerations have been present in the minds of those engaged in the trade during many years, and several sailing vessels have been adapted at different times for the purpose of securing the advantages which the carriage of petroleum in bulk offers. Before passing to the consideration of these plans, as well as of later proposals, I may observe that there are certain arrangements which are necessary features of all well-considered methods. These are:

1st. Provision for the expansion of the oil under an increase of temperature. It may be taken that petroleum increases in bulk about one gallon in 200 for an increase in temperature of 10° Fahrenheit, and as considerable variations in temperature are likely to occur on certain voyages, it is obviously necessary, if the tanks are to be saved from leakage, or even bursting, that space should be afforded to admit of any probable expansion taking place. For an increase in temperature of 40° Fahrenheit the increase in volume would be about two per cent., and in some of the plans with which I am acquainted this degree of expansion has been allowed for. I may add that it is usual not to completely fill either barrels or cases, space being left for expansion.

2nd. Provision for keeping each tank full by automatically supplying any loss due to leakage, or to contraction consequent upon a fall in the temperature of the oil. This is necessary for two reasons. In the first place, if the level of the oil in the cisterns were allowed to fall, it would be free to rush from side to side as the vessel rolled, and thus do damage which might result in the loss of the vessel. In the second place, any depreciation in the height of the oil over a space of even moderate extent seriously reduces the *effective* metacentric height, and renders the vessel less stable in the upright condition.

To make this clear let it be supposed that the vessel in Fig. 1 (Plate I.), which contains oil with a free surface O O_1, becomes inclined through a small angle O S H. The wedge of oil O S H is transferred to the position O_1 S H_1, and consequently the common centre of gravity of hull and cargo moves away from its former position G in the middle line to a new position G_1. The centre of buoyancy also moves from B to B_1 in the ordinary way. We shall have, therefore, the resultant upward pressure of the water, equal to the weight of the laden vessel, acting vertically through B_1, and an equal weight downwards through G_1. The distance A M between the points in which the lines of action of the two forces cut the middle line of the vessel measures the righting moment at small angles of inclination, in the same way as under ordinary circumstances G M does. I have, therefore, called it the *effective* metacentric height. If the extent of free surface be large enough to cause G_1 to pass beyond the vertical through B_1, the vessel will be unstable in the upright condition. If the vessel has a ballast tank beneath the oil cisterns in which leakage to any considerable extent can collect, an additional wedge of oil is transferred from one side to the other as the vessel inclines, as shown on Fig. 2 (Plate I.), resulting in a further decrease in the *effective* metacentric height.

To illustrate the importance of this point I will suppose a "Three-deck" vessel 250 feet long, by 33 feet broad, with a load displacement of 3,500 tons, to have a midship compartment 30 feet long extending from side to side. If the level of the oil in such a compartment were slightly lowered, the *effective* metacentric height would be reduced by as much as 7 inches, and if the leakage were to collect in the bottom of the vessel over the same area, we should have, in the case of a flat-bottomed vessel, nearly double this decrease in metacentric height. It will be easily understood that such a loss of metacentric height might in practice be attended by serious consequences, and hence it is very desirable to minimize the area over which leakage at any one point would have effect, by subdividing the hold space, as well as by making good any loss due to leakage. By fitting a longitudinal middle line bulkhead the loss of *effective* metacentric height by a fall in the level of the oil over the same area is reduced to one fourth, and by sub-dividing the oil-carrying space by numerous transverse bulkheads the extent of the free surface in connection with leakage in any one compartment becomes reduced, and the consequent danger due to a loss of initial stability correspondingly diminished.

Closely connected with this part of the subject is the question of the proper proportion between the breadth and depth of a vessel designed to carry petroleum in bulk. If the breadth be great in relation to the depth, and the vessel has, in consequence, great initial stability, and is, therefore, a heavy roller, a depreciation in the level of the oil will be followed by an agitation tending to cause the compartment to strain and leak. If, on the other hand, the vessel be so narrow as to have only a small metacentric height, any fall in the level of the oil in one or more compartments will be liable to render her unstable in the upright condition.

The suitable relation between the breadth and depth can, of course, only be settled in each case in connection with the proposed arrangement of tanks, but it is obvious that vessels in which the oil extends to the inside of the plating of the bottom, and in which the crown of the tanks is fitted some distance below the upper deck, as well as those which carry only a limited amount of oil in the 'tween decks, should be made relatively narrower than vessels which have the tanks so arranged that the position of the common centre of gravity approximates to that usual with ordinary cargoes.

3rd. Provision for the escape of the gases given off by the oil. These gases are given off by certain kinds of oil more or less at *all* temperatures, and if this precaution be not taken the presence of an admixture of explosive gases will constitute a source of danger.

4th. Special precautions to prevent the passage of any of the oil into the boiler space. This is usually effected by fitting transverse bulkheads on two adjacent frames on the fore side of the boiler space, and by either filling the space between them with water, thus forming a "water-bulkhead," or by providing special pumping arrangements for removing any leakage. To avoid the necessity for fitting double bulkheads both before and abaft the engine and boiler space, as would be the case if that compartment were situated amidships, it is customary in new vessels to place the machinery abaft the oil tanks. One other advantage of this arrangement is that it minimizes the danger which is caused by sparks from the funnel alighting on the deck. The difficulty involved in making the shaft tunnel oil-tight is also obviated in this way.

Having enumerated the chief considerations inseparable from the safe carrying of petroleum in bulk, I shall proceed to notice the several plans that have so far been adopted, or are being carried out.

The practice of transporting petroleum in bulk cannot be said to be altogether modern. So long ago as the middle of the last century we find that the Persians carried the crude oil obtained in the neighbourhood of Baku across the Caspian in bulk; but if we are to believe Hanway, they employed such wretched vessels in the trade that they met with but moderate success. For more than a century the Persians found no imitators in Western Europe. In more modern times, the first vessel in which, so far as I am aware, it was attempted to dispense with casks, and to carry oil in bulk was the wooden ship "Charles," of 794 tons. In that vessel two rows of iron tanks, constructed to fit the form of the section, were placed in the hold, and two other rows in the 'tween-decks. She carried 59 such tanks in all, those in the 'tween-decks holding about 12 tons of oil each, and those amidships in the hold about 30 tons. The tanks were not connected in any way with each other, but were separately filled and emptied, and no provision was made to supply with oil any waste due to the leakage which, owing to the weak construction of the tanks, was of common occur-

rence. It was, however, the practice of the captain to add salt water to the oil in those tanks which were found to leak on the voyage. As the cargo was unrefined this expedient did not injure the oil. The "Charles" was successfully employed during three years, from 1869 to 1872, in the trade between the United States and Europe. In the latter year she was burnt.

Several wood vessels were engaged about this time carrying petroleum in bulk between America and Havre and Antwerp, but most of them disappeared. Very little is known of the details of the arrangements made in those vessels, but I am in possession of very full information regarding some of the later ones which are stated to have been fitted out in a manner superior to the bulk of the vessels engaged in the trade. Among these were three Norwegian vessels, Fig. 3 (Plate I.), belonging to the same owner, adapted for this purpose in 1878. They were fitted all fore and aft with a 3½-inch middle line bulkhead extending to the height of the hold beams which were close ceiled on the underside, the ceiling forming the crown of the tanks. The hold was further divided into compartments by several wood thwartship bulkheads to the height of the hold beams. Inside the ceiling proper of these vessels was laid a lining of felt, and within this again an inner wood ceiling. Midway between the middle line and each side, stanchions formed of 3½-inch planks bolted together were fitted to every hold beam, but for a length of a few feet at the upper end the middle plank was omitted to enable wash boards, marked A on Fig. 3, to be reeved through. The wash boards ran all fore and aft, and were intended to prevent the rapid rush of the oil from side to side which would otherwise take place as the vessel rolled, in the event of the tanks becoming only partially filled. In the 'tween decks a number of iron tanks were fitted, but I understand that in the "Lindesnœs," the only one of the three still engaged in the trade, they have been removed, and the space occupied by oil in barrels. One of the three vessels disappeared after a few voyages, while another, the "Nordkyn," grounded in the river Delaware in 1879, and discontinued thenceforth to carry oil in bulk.

Another vessel very similarly arranged was the wood barque "Fanny," of 1,153 tons, which disappeared on her first voyage in 1880. She differed from those just described in having a coating of 2½ inches of cement, Fig. 3, laid upon the ceiling in lieu of felt, and within this again an inner ceiling 1½ inches thick. The "Fanny" carried oil in barrels in the 'tween decks.

In addition to the foregoing, I find there were three iron sailing vessels built in the year 1863 for the petroleum carrying trade. The "Ramsey," of 821 tons, built in the Isle of Man, and the "Atlantic" and "Great Western," each 416 tons, built on the Tyne.

The "Ramsey" had a complete iron lower deck, and the lower hold was divided into small compartments by a central longitudinal bulkhead and several transverse bulkheads.

The other vessels had the centre longitudinal and transverse bulkheads extending to the upper deck, and the fore and main masts, which were of iron, were capable of being filled to a considerable height above the deck with oil with a view to keeping the compartments under pressure.

Whether these vessels actually carried petroleum or not I am unable to say, but certainly they were, within a very short time after they were built, employed in ordinary trade.

The first steamer built specially for the carriage of oil in bulk was completed in 1872 by Messrs. Palmer and Co., Limited, for a Philadelphia firm. She was named the "Vaderland." Her registered dimensions were 320·5 × 38·5 × 30·9, and her gross tonnage 2,748. She was intended for the trade between Antwerp and the United States, but the Belgian authorities refused to allow cisterns to be erected to warehouse the cargo, and the American authorities declined to permit the vessel to carry passengers as intended. Just at that time, too, the owners were offered a favourable contract by the Belgian Government, and in consequence, she has never been engaged in the special trade for which she was designed.

Notwithstanding the non-employment of this vessel in the oil trade, a brief account of the arrangements for the carriage of oil in bulk in iron steamers thought suitable in 1872 will not be without interest at the present time. The machinery in the "Vaderland" was fitted aft, Figs. 4 and 5 (Plate I.), and in the main hold throughout a length of about 162 feet, a longitudinal middle line bulkhead extended to the height of the hold or third tier of beams, below which the oil was to be carried. The main hold was further divided to the height of the hold beams by four transverse bulkheads into ten separate compartments. The hold beams, which were very deep, were plated both above and below, and each compartment communicated with the upper deck by means of an oil-tight trunk hatch, extending to that deck, as shown on Fig. 4.

As it was not proposed in this vessel to permit the oil to extend to the outer skin, an inner skin was fitted as on Fig. 4, the space between the two skins being 26 in. at the middle line, diminishing to 20 in. at the upper turn of the bilge, and above to the height of the hold beams. The large trunk hatchways were intended to serve the purpose of feeders in the event of leakage, as well as to hold the excess of oil caused by expansion under increase of temperature. Although in this vessel the hold containing oil was separated from the boiler space by a thwartship coal bunker eight feet long, so great was the desire to prevent even the possibility of accident through leakage, that three transverse bulkheads, marked A on Fig. 5, were fitted within a space of two feet.

The "Vaderland," was followed in 1873 and 1874 by the "Nederland" and "Switzerland" respectively, two vessels of about the same size as the former, and similarly constructed, with the exception that, as favourable contracts were offered in other trades, as in the case of the

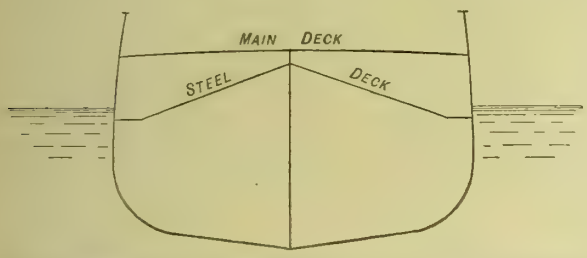
"Vaderland," the machinery was not placed aft. Exceptional care was taken in view of the nature of the cargo proposed to be carried in these vessels to secure good workmanship, and the weight of the finished hull was much greater than that of the ordinary cargo-carrying vessel of the same size. They are still afloat, but as I have said they were never employed in the trade for which they were designed, though I believe the idea of carrying oil in bulk in one or more of them has not been entirely abandoned.

No subsequent attempt has been made, so far as I am aware, until quite recently to employ steam shipping for the purpose of transporting petroleum in bulk across the Atlantic. It was not on the Atlantic, but on the Caspian, that the problem was first brought to a successful issue. The petroleum industry in that region long languished under a Government monopoly which afforded no incentive to improvement either in the process of refining or distribution. In 1872 the total amount of petroleum refined yearly did not exceed 24,800 tons. When a heavy excise duty was substituted in that year for the monopoly, the production immediately rose to 64,000 tons per annum. In 1877 it had grown to 242,000 tons, and on the abolition of the excise duty it rose immediately to 320,000 tons. But the scarcity of wood in the locality, and the consequent great cost of barrels compared with that of the oil they contained, led, or rather forced the Messrs. Nobel, to whom the credit of the new departure is due, to turn their attention to the question of the carriage of petroleum in bulk. They accordingly had some vessels built for this purpose, and in 1879 they began to run from Baku to the mouth of the Volga.

These steamers, several of which are of large size, being 250 feet long and 28 feet broad, with a draught of water of 11 feet, now number about 80 in all, and they perform the voyage between the two ports named with marked success as regards both economy and safety. They are not all of one type. Some of the later ones carry the petroleum in cisterns, of which the bottom and sides are formed by the outer plating, while others are fitted with tanks which are independent of the structure of the vessel. Some of the former have two longitudinal bulkheads running through the forehold, and several transverse bulkheads further sub-divide the oil space. The engines are placed amidships, and abaft these in the after hold are fitted two cylindrical vertical tanks rising above the level of the deck.

These vessels, in addition to carrying petroleum in bulk, burn liquid fuel, which consists of the residue left from the petroleum after conversion into kerosine. They do not, of course, meet with such severe weather as is experienced in the North Atlantic; but even on the Caspian, storms severe enough to test their sea-going qualities are of frequent occurrence. As a result of six years' experience of the working of these steamers, many of which have been built at Motala in Sweden, it is found very necessary, whatever be the system adopted, that the workmanship be of first class quality,

all seams are at least double riveted, and no tightening material is used. In all cases a protection space or water bulkhead is arranged between the stokehole and the after end of the cisterns, and similarly a double bulkhead is fitted forward between the cisterns and the crew space. The galley is placed abaft the cisterns, and the latter are capable of being filled or emptied without undoing manholes or lids.



In some of the smaller vessels built at Motala for the Caspian trade, the roof of the cisterns has been formed of steel plating, sloped, as shown in the sketch.

It is claimed for this method that the slope prevents the oil striking the roof of the cistern too violently, but it is somewhat difficult to see how such a result is obtained under the plan.

While the practice of carrying petroleum in bulk has met with so much success, and is regarded with so much favour on the Caspian, so great has been the mortality among the wooden vessels engaged that it has been gradually going out of favour in the Atlantic trade. Nearly the whole of the oil so shipped during the last twelve years has been either in barrels or cases. Recently, however, a further step towards carrying oil in bulk has been made upon improved principles. Last year the large composite ship, "Andromeda," of 1,871 tons nett, owned by a German firm, was specially fitted with tanks for the oil trade. Her registered dimensions are 270·6 ft. × 37·1 ft. × 25 ft., and she carries 72 tanks in all, two rows resting upon the ceiling in the hold, two rows upon the orlop beams, and two other rows upon the 'tween deck beams. Each tank is provided with a three-inch pipe for filling and discharging, as well as an air and a sounding pipe. All the filling pipes are branches from one main pipe, which runs all fore and aft, and communicates with the pumps. An expansion cistern in connection with the tanks in the lower hold stands upon the orlop beams, and similar cisterns in the 'tween decks and in the hatchway on the upper deck communicate with the tanks on the orlop and 'tween decks respectively. A passage way about three feet wide, into which the connecting pipes are carried, is left between the tanks at the middle line. The "Andromeda" has already successfully completed two voyages between New York and Germany.

In September of last year an American merchant, Mr. L. V. Sone, of New York, patented a plan for "improvements in vessels for transporting liquid cargoes in bulk," and has fitted up the wooden barque, "Crusader," of 643 tons, in accordance with the patent. The vessel has made three voyages between the United States and this country with safety, and has delivered her cargoes in first class condition. A plan of the arrangements is shown on Fig. 6 (Plate II.). They consist of three tiers of circular cylinders placed tier above tier. The vessel carries 47 of these cylinders, arranged in such

lengths that an end of each is located beneath a hatch, and each one is fitted so as to be independent of all the others. To each cylinder is attached a pipe (A) which passes up into the hatch above, to be connected with the hose for filling or emptying the cylinder. A separate pressure-pipe (B) attached to the top of the cylinder passes also up through the hatch and extends to some height above the deck. Its purpose is to carry away any vapour that may be given off by the oil. Each of the pressure pipes is also connected by a branch with a pressure tank or reservoir (C) standing upon the deck. The purpose of this tank is to keep the liquid in the cylinders under constant pressure, and to supply any waste due to leakage. It also serves as an overflow tank into which the oil finds its way when an increase of volume occurs through an increase of temperature.

A certain amount of disadvantage, it may be observed, results from having the same overflow tank for all three tiers of cylinders, inasmuch as, by the plan, the lowest tier is subjected to a much greater pressure than those above, and has, therefore, to be made correspondingly stronger. In other plans the difficulty is overcome by having a separate reservoir for each tier. The pumping arrangements in this vessel are such that any one tank can be filled or emptied or otherwise dealt with, without interference with any of the others, and it is claimed for the plan that by it the whole of the oil is kept under perfect control. That it enables petroleum to be carried with as great safety as other descriptions of cargo appears obvious, and I understand that it is in contemplation to build some iron steamers of large size, to be fitted on the same principle.

The first steam vessel adapted in this country for the carriage of oil in bulk was the "Fergusons," of 1,551 tons gross, altered by Messrs. R. Craggs & Sons of Middlesbrough in the latter part of last year. Two rows of large iron tanks, Fig. 7 (Plate II.), are fitted in the hold and two others in the 'tween decks. These tanks are specially shaped to fit the form of the vessel and fill nearly the whole of the hold and 'tween deck space, a passage way of two feet being left at the middle line. They are filled by branch pipes from a five-inch main carried along under the upper deck beams in the fore and after holds, and are emptied by the same system of pipes, each tank being capable of independent connection with the pumps. To keep the tanks quite full, and at the same time to provide for the expansion of the oil, a regulating tank is fitted in the 'tween decks, and connected with each of the system of tanks arranged in the hold. A second tank (A), placed in the hatchway on the upper deck, is similarly connected with the 'tween deck tanks. The separate regulating tanks are fitted in this instance to obviate the great pressure that would be brought upon the lower tier if they communicated with the tank on deck.

To take up any overflow from the regulating tanks, and also to furnish if necessary a reserve supply for filling those tanks in the event of leakage, an overflow cistern is fitted in the hold immediately beneath the regulating tanks. The tanks are ventilated by means

of branch pipes B, led into a main pipe running all fore and aft, and connected with ventilators fitted on the deck. To guard against the ignition of vapour, the mouth of each ventilator is covered with a sheet of gauze, and the sluice valves usually fitted to cargo vessels have been removed from the bulkheads to the engine and boiler space to prevent the escape of any leakage from the tanks into that compartment. The chief objection to this arrangement appears to be the difficulty of gaining access to the sides and bottom in way of the tanks, thereby precluding any examination of the interior of the vessel, or repairs being effected without considerable expense.

Another plan for improvements in the construction of "navigable vessels for carrying "liquids in bulk including cargoes of a volatile character such as petroleum, turpentine "and the like" has been proposed by Mr. Swan, of the firm of Sir W. G. Armstrong, Mitchell & Co., Limited. By Mr. Swan's method the hold is divided by a middle line longitudinal bulkhead, and further sub-divided by a series of transverse bulkheads into compartments bounded at the top either by the vessel's deck or a specially fitted platform. As in some of the Caspian steamers, the oil extends to the skin of the vessel, and to each compartment are fitted one or more trunkways, either circular in section or of any other convenient form, partially filled to ensure that the corresponding compartment is full, and also to provide for the contraction or expansion of the oil. A number of ways in which the trunkways may be fitted are suggested by Mr. Swan. One feature of the method is the arrangement for recording the height at which the liquid stands in the trunkway. For this purpose a piston is fitted to the trunkway and floats on the liquid, a graduated rod attached to it passing up through a stuffing box in the cover. A small pipe in the cover of the trunkway admits of the escape of vapour. As in other plans, by a suitable arrangement of pipes each compartment is capable of being separately filled or emptied. To provide for any leakage through the end bulkheads of the compartments a well is formed on the fore side of the boiler space, and arrangements are provided to enable the liquid to be pumped back into the trunkways. Sir W. G. Armstrong, Mitchell & Co., Limited, have under construction two vessels designed in conformity with this plan, and the efficiency of one of these vessels which has been completed will soon be tested. She is named the "Glückauf," her registered dimensions being 300·5ft. × 37·2 ft. × 23 ft., and gross tonnage 2,297 tons.

Another steam vessel, the "Sviet," Figs. 8 and 9 (Plate III.), built for the Russian Steam Navigation Company last year by the Motala Company, who have had great experience in the building of vessels intended to carry petroleum in bulk, has been specially designed to convey the oil from Batoum to European ports, and differs in her construction from those already described. Her engines are placed aft, and double bulkheads, marked A on Fig. 9, forming a "water bulkhead," are fitted on the fore side of the cross bunker. Forward of this, for a length of 140 feet, the vessel is divided by a middle line longitudinal bulkhead, and by several transverse bulkheads extending to the upper deck. In each of the com-

partments so formed a cistern is constructed, the sides of which are built within the sides of the vessel, leaving a passage of about three feet. Similarly, a space of about 20 inches is left between the upper deck and the top of the cistern. The plating of the top of the cellular bottom with which the vessel is fitted forms the bottom of the cisterns, which are further divided by a steel watertight flat into an upper and a lower tier. There are 16 such cisterns in all.

On the fore side of the foremost oil cisterns two bulkheads about two feet apart, marked B on Fig. 9, are fitted, forming what the builders term a "gas protection," and before this are placed the powerful pumps for emptying the cisterns. Each cistern is provided with a trunk three feet by two feet six inches, extending to about two feet above the deck, and covered by a watertight crown in which a manhole and an air and sounding pipe are fitted. For filling the cisterns the oil is conveyed in pipes from the wharf to the feeding cistern C, Fig. 9, placed forward on the deck, and from this a pipe is led on each side into the pump room and connected each with a fore and aft pipe carried between the cisterns and the vessel's side. By means of branches from the fore and aft pipes the several cisterns are filled or discharged, the arrangements being such that each cistern can be filled or emptied independently. A spare cistern is provided in the pump room to supply any loss due to leakage. The pumps are able to discharge the whole of the cargo, about 1,700 tons, in five or six hours with proper facilities for discharge. A complete arrangement of pipes and ventilators is provided for ventilating the space around the oil cisterns. The sides of the cisterns are not connected with the sides of the vessel, the object being that they may remain intact in the event of concussion or damage to the latter. It is the practice, however, to drive soft wood wedges about four feet apart between the tank sides and the two plate stringers on each side as shown on the section.

It is claimed by the builders of the "Sviet" that the following are among the advantages of the arrangements adopted in that vessel: the cisterns are at any time open to inspection, and, in case of need, to repair also; they are easy to fill or empty without being opened, while the system of ventilation has shown itself to be in every way practical and satisfactory. But, however complete may be the design and arrangement of the tanks in this vessel, the plan is one which, from its cost, has hitherto failed to commend itself to the shipowners of this country. For very little more than the sum which the "Sviet" cost to build it would be possible to construct a steamer on other plans, similar to some described in this Paper, capable of carrying nearly twice as much cargo. It should be added that the "Sviet" has quite recently brought a full cargo of kerosine to London from Fiume, when I had an opportunity of inspecting her before the discharge of the cargo, and found that it had been carried with little or no leakage on the voyage.

Another plan for the carriage of petroleum in bulk in steam vessels is that adopted by Messrs. Wm. Gray and Co., of West Hartlepool, in a new iron vessel named the "Bakuin,"

Figs. 10 and 11 (Plate IV.), now completing for a London firm. Her registered dimensions are 260ft. × 36ft. × 17·4 ft. and the gross tonnage 1,527 tons. The great bulk of the oil in this vessel is carried beneath the lower deck, a novel feature of which is that the beams are given a camber in the opposite way to that usual in ships. The object of this sagging of the beams at the middle is to enable the tanks to be completely filled and efficiently ventilated. The air, while the tank is being filled, or the vapour given off at sea, collects naturally under the deck near the beam arms, from which it is led away by means of suitable ventilators. A longitudinal middle line bulkhead extending to the height of the middle deck divides the main hold, and transverse bulkheads further divide it into compartments of from 32 to 36 ft. in length.

As shown on the sketch of midships section, the "Bakuin" has a cellular bottom, the crown of which forms the floor of the oil tanks. Above the cellular bottom to the height of the 'tween decks the oil extends to the side, as in some other plans. In the 'tween decks, and of the shape shown on the section, are built a number of additional oil compartments. They do not extend either to the side of the vessel or to the deck above, and it is claimed for this plan that while the oil in the main hold can never reach a high temperature owing to the immersion of the vessel, the tanks in the 'tween decks, by being so formed, are kept at a much lower temperature in hot climates than if they extended to the sides. In the event, too, of injury to the hull at this part by collision or otherwise, the tanks would under ordinary circumstances escape injury.

As in other vessels, the machinery is placed aft, and a double bulkhead, marked A on Fig. 11, is fitted before the boiler space, and another at the fore end of the foremost oil compartment. The hold is further separated into two distinct divisions by an additional pair of adjacent transverse bulkheads (B), as shown on the longitudinal plan. The object of this arrangement is to allow of oils of different qualities being carried on the same voyage without any danger of their mixing. Arrangements have also been made by which, with oil in the hold, other descriptions of cargo may be carried in the 'tween decks. With this object expansion tanks (C) formed on the middle deck communicate with the cisterns in the hold, and are capable of being closed, air pipes being fitted to pass through the cover and above to the upper deck. Additional expansion tanks D built on the roof of the 'tween decks cisterns, within the area of the upper deck hatchways are for use when both the tanks in the hold and 'tween decks are filled.

The whole of the valves which regulate the filling or emptying of the tanks are conveniently placed in the engine house, and by means of an arrangement of floats, connected with wires, the level of the oil in each tank can be ascertained at the same place. Great care appears to have been taken in the construction of the "Bakuin" to avoid all possible sources of risk from fire. She is to be lighted by electricity; the cabins are to be heated by steam instead of by fires; and the cooking will also be done by steam. It is estimated that this vessel will carry

1,950 tons of oil; and the pumping arrangements are such that, with proper facilities for discharge, the cargo can be emptied in about 12 hours.

A few words regarding the riveting of those parts of the "Bakuin" required to be oil-tight will be of interest. Owing to the fact that oil has far greater penetrating power than water, and finds it way through seams that are quite impervious to the latter, it has been found necessary to space the rivets in both edges and butts closer than is usual in shipwork, while especial care has to be taken that the holes conform well with each other, and that the workmanship is of a superior character. In the top of the cellular bottom which forms the sole of the cisterns the plating is $\frac{6}{10}$in. thick, and the rivets $\frac{5}{8}$in. in diameter spaced $2\frac{1}{4}$ ins. apart from centre to centre. In the shell plating amidships, the strakes of which are alternately $\frac{10}{16}$in. and $\frac{11}{16}$in. thick, the rivets are $\frac{7}{8}$in. and are spaced from $2\frac{1}{2}$ ins. to $2\frac{3}{4}$ ins. apart from centre to centre in the edges, and from $2\frac{3}{4}$ ins. to 3 ins. in the butts, Fig. 12. Where $\frac{3}{4}$in. rivets are used they are spaced from $2\frac{3}{8}$ ins to $2\frac{1}{2}$ ins. from centre to centre. The rivets connecting the shell plating to the frames are from 6 ins. to $6\frac{1}{2}$ ins. apart. In the transverse bulkheads the overlaps are riveted with $\frac{5}{8}$in. rivets spaced $2\frac{1}{4}$ ins. apart. This spacing of rivets is closer than in any vessel yet built in this country for oil carrying purposes, and from what has come under my notice, I question whether much wider spacing of rivets than this—even with the best workmanship—would ensure practical oil-tightness.

Yet another plan, Figs. 13 and 14 (Plate V.), proposed by Messrs. Hawthorne, Leslie & Co., in a vessel which they contemplate building, remains to be noticed. The vessel is fitted with water ballast in the ordinary way, the crown of the tank forming the bottom of the oil cisterns. The machinery is placed aft, and before this the hold is divided by two longitudinal bulkheads, and by transverse bulkheads into 18 separate compartments. Under the plan the steel upper deck forms the crown of the tanks, and the ordinary hatchways formed in the deck serve the purpose of overflow tanks, each hatch being made broad enough to serve for the three tanks. The carrying of the oil up to the underside of the weather deck as in this case, and in a vessel being altered by the same firm, is entirely novel, and in view of the possible dangers which it may entail, must be regarded as an experiment.

In addition to the vessels already referred to a number of other steamers are either being altered, or are proposed to be altered, to carry oil in bulk. Among these are the "Chigwell," of 1,699 tons, "Presnitz," of 1,639 tons, "Marquis Scicluna," of 1,655 tons, "Petriana," of 1,672 tons, and "Mount Edgcumbe," of 1,667 tons. As in these vessels it is intended to carry the oil out to the skin plating it is necessary to take great pains to secure the oil-tightness of all seams and joints. To effect this purpose Messrs. Hawthorne, Leslie & Co., in altering the "Chigwell," removed the whole of the rivets within the boundary of the oil tanks, rimed and countersunk the holes both inside and outside, and re-riveted the plates with boiler rivets, as in Fig. 12 (Plate IV.).

To enable the whole of the seams and straps to be caulked on the inside the frames, stringers, and keelsons were removed, and after the caulking replaced. The seams inside were also chipped, and the edges of the butt-straps planed to insure good caulking, and for the same reason the back row of rivets in treble riveted straps was made complete. In way of the frames the seams of the shell plating were riveted together independently so as to avoid three-ply riveting, the necessary connection with the frame being obtained by an additional rivet above and below the seam. In places where the top of the double bottom, deck, or hold stringer crossed the butts of the outside plating the straps were removed and secured on the outside of the vessel. It was not found necessary to renew any of the plates in the "Chigwell," as the holes were found generally to be very fair, and the butts close.

The general arrangement of the oil tanks in the "Chigwell" is shown on Figs. 15 and 16 (Plate VI.). A middle line bulkhead divides the oil compartments which extend from the top of the ballast tanks to the underside of the iron upper deck, except in way of the cabins in the bridge, where a separate roof is fitted to the cisterns some two feet below the deck. As already explained, the oil in this vessel is brought into direct contact with the plating of the hull, great pains having been taken to secure oil-tightness in the seams and butts. The ordinary hatchways have been made to serve the purpose of expansion tanks, and the transverse bulkheads are so arranged, where possible, as to admit of each hatch supplying four compartments. It should be added that the oil is prevented coming into contact with the plating of the shaft tunnel by a separate casing built around it.

The plan of making the outside plating of the vessel form the sides of the cisterns in which the oil is to be carried, although adopted with success on the Caspian, has only now begun to be employed in vessels engaged in over-sea voyages. Great care, as has been shown, has been taken to make these vessels oil-tight, and doubtless for some time they may be found to be so; but it must be borne in mind that vessels have to encounter heavy seas, and frequently come in contact with wharves, barges or other structures with sufficient force to start the riveting and caulking and cause leakage, so that the plan may be said to be yet on its trial.

From the foregoing brief description of the several plans that have been employed in fitting vessels for the carriage of petroleum in bulk it will be seen that much care has been taken to guard against many of the sources of danger to which vessels in that particular trade are liable. In practice a great deal must depend, however, upon the intelligence with which the cargo is handled, and upon the precautions taken to prevent accident. Much of the safety which has attended the carriage of petroleum in bulk on the Caspian is due to the very great care exercised, especially in later years by those in charge. No open light is allowed on board during loading or unloading, and this regulation is also enforced in the pump room. The electric light has been recommended with a view to

the reduction of risk from fire to a minimum, and it will probably be brought into general use in vessels engaged in this trade.

But notwithstanding the necessity for great care enjoined upon those engaged in handling this description of cargo, it is not possible to provide absolutely against the carelessness of seamen. Two serious explosions resulting in the total wreck of the vessels on which they occurred are known to have taken place. One occurred on the Volga on board a barge without machinery, and was due to the carelessness of one of the crew, who let down into a tank a lighted candle attached to a string to ascertain the height of the surface of the oil. The candle burnt the string, and it fell into the oil, and in a short time an explosion took place which wrecked the barge. In the other case a large steamer was loading oil at Baku in a storm, and not being moored with sufficient care she heeled over, thereby pulling the hose out of the tank that was being filled. The oil ran along the deck to the galley where a fire was burning, and ignited. In a few minutes the whole of the vessel was in flames; explosion followed explosion, and the vessel became a total wreck.

While, as these instances show, the carriage of petroleum in bulk on the Caspian has not been wholly unattended by danger, it is in the carriage of the partially crude oil from Batoum to Fiume and other Austrian and Italian ports that most risk is run. The crude oil gives off gas at a low temperature, and is very inflammable and explosive. Great carelessness, it is stated, is observed in loading these cargoes at Batoum. The barrels are very weak and irregular in size, and consequently bad stowage is made, and much of the oil is lost by leakage.

In a letter received from a very intelligent captain who was engaged in this trade, he stated that on unloading at Fiume a few barrels were found damaged, but many were partly empty, and crude oil was found in the hold to the depth of a foot. He had fortunately taken the precaution to close the sluice valves and cement them over to prevent the oil running into the boiler space. He also fitted ventilators to each hold with gauze covers to prevent sparks entering, and sawdust was strewn among the barrels to prevent the friction between them firing the gas. Two cases are quoted by the same authority in which steamers have been burnt through oil escaping into the boiler space. One of these was the German steamer "Octavia," built at Fiume two years ago, and the other was an English steamer. He was also witness of the burning of a Russian steamer very recently, one day out from Batoum, laden with a cargo of crude oil. Under the bulk system there would be little or no greater danger involved in the carriage of crude oil than of refined.

There are not wanting signs that many of the shipowners of this country are awakening to the necessity of taking immediate steps to secure participation in an industry

which is at the present time almost entirely in the hands of foreigners. As I have said, one or two steamers have been already so altered as to adapt them for the carriage of oil in bulk, and a number of other vessels are undergoing the necessary alterations, while some new steamers specially designed are being built. The petroleum industry is a growing industry, and promises to open up a large field for those who are enterprising enough to adopt the simplest, cheapest, and most expeditious plan of carrying the oil. The following table gives the quantity exported in tons annually from America for the last 15 years :—

Year.	Tons.	Year.	Tons.
1870	334,000	1878	997,000
1872	427,000	1880	1,247,000
1874	729,000	1882	1,647,000
1876	717,000	1884	1,510,700
		1885	1,531,000

It will be seen from these figures that the amount of petroleum exported annually has been steadily growing, and will no doubt continue to grow. Even if it be true, as rumoured in some quarters, that the Pennsylvanian oil tract shows signs of exhaustion, this fact will not it is thought, deter shipowners from entering upon the trade. There is believed to be sufficient oil in Washington county, and in the State of California to last for very many years.

If we turn to the consideration of the future of the Russian oil industry, the prospect is still more reassuring. The wells near Baku have been worked for centuries, and still show no signs of exhaustion. They occupy at present only three and a half square miles out of a total of 1,200 square miles over which petroleum is found. The supply in that region may, therefore, be regarded as practically inexhaustible, while in addition there is the prospect of additional supplies from Burmah, India, Egypt, and other parts of the world. The total quantity of oil refined in Baku annually has been steadily growing in amount. The following figures give the production in tons per year since 1878 :—

Year.	Tons.	Year.	Tons.
1878	97,550	1882	202,000
1879	110,000	1883	206,000
1880	150,000		
1881	183,000	1884	348,400

These figures are capable of very great expansion. The oil is at present brought from Baku to Batoum, a distance of 560 miles, along a single line of railway in tank waggons, but if the industry is to be adequately developed it will be necessary to lay one or more pipes between the two towns, just as the Pennsylvanian oil wells are connected by the pipe system of the National Transit Company with New York, Philadelphia, Baltimore, and other large towns, and to pump the supply into reservoirs at Batoum ready for shipment. It will also be necessary to provide facilities for the rapid discharge of the cargoes. A vessel loading in bulk can be filled in a few hours, and should be discharged in about the same time. To effect this, large reservoirs will require to be erected at all the principal towns to which petroleum in bulk is to be shipped, after the manner of the reservoirs on the Volga and at Fiume and other places, and the cargoes simply pumped into them from the vessels' holds.

Recently, when the "Crusader" brought a cargo of oil to London, it was conveyed in pipes from the vessel in the Regent's Canal Dock to barges lying in the Limehouse Cut, and conveyed in these to the wharf of the Atlantic Storage Company. The "Sviet's" cargo was similarly discharged. This method of discharge extended over several days, whereas, had suitable reservoirs been erected, the vessel's pumping power was such that she could have been emptied in a few hours. Up to the present time, owing to deficiency of accommodation at the port of discharge, the vessel has never been unloaded in less than fifteen hours.

Into the method of retail I do not propose to enter, further than to say that if the oil is to be conveyed to the consumer at the lowest possible price, and the demand thus stimulated to its fullest extent, some such conveyance as the tank waggon shown on Fig. 17 (Plate VII.), recently devised by Mr. Edward Phillips, of Bishopsgate Street, London, will have to be resorted to.

The preceding remarks apply to the conveyance of refined petroleum for illuminating and other purposes, but the question of the use of *astatki* as a liquid fuel for the propulsion of steam vessels is one which is increasing in interest. The experience gained in the use of oil in the propulsion of steam vessels on the Caspian, as well as in this country, shows that the engineering difficulty has been overcome, and that no obstacle exists to its practical application for comparatively short voyages. There is also no doubt that should the time arrive when it can be used economically, engineering skill will be able to overcome any difficulties which may arise in its use for voyages of any length. Shipowners have been reproached with a lack of enterprise in neglecting, up to this time, to adopt liquid fuel as a substitute for coal. The question, however, which has to be faced before such a revolution in the means of propulsion can take place is that of *cost*. Although weight for weight, the evaporating power of petroleum has been shown to be nearly double that of coal, the price at which the residuum of crude oil, *astatki*, can be

supplied in this country renders it at present prohibitive as compared with coal for the purpose of propulsion.

The price of *astatki* at Baku varies from time to time from 4d. to 1s. 3d. per ton, but the carriage by rail to Batoum raises the cost at the port of shipment to about £1, and if to this be added the freight to this country, which amounted to 22s in the case of the s.s. "Sviet," the total cost on delivery would not be less than £2. 2s. With these figures before us, it must be evident that while the best steam coal can be shipped at Cardiff at say 9s. per ton, liquid fuel, even with its superior evaporating power, cannot yet be economically used in competition with it. In view, however, of the reduced cost which may be looked for as the result of the awakened enterprise now displaying itself in the production of vessels specially adapted for its conveyance, of the reduction in the cost of transit which must follow upon an improvement in the means of communication between Baku and Batoum, (unless as a result of the step recently taken by the Russian Government, by which Batoum ceases to be a free port, the development of the industry be hindered,) and of the fact that large supplies of petroleum are being found in all parts of the world, the day may be nearer than some imagine when the trade may be largely increased by the conveyance of this commodity as a substitute for coal in the heating of steam boilers.

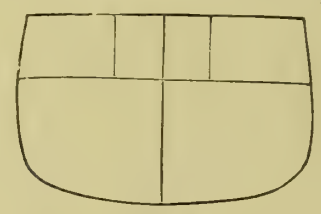
In the meantime there is, as has been shown, a large field of enterprise open for shipowners in the conveyance of petroleum for illuminating and other purposes, and from the great interest recently awakened in this country in the subject, we may doubtless look forward to a great increase in the number of vessels, as well as to improvements in their arrangements, to render them more suitable for this purpose, which will thereby add to the prestige of British shipbuilders and owners, while developing a remunerative branch of commerce.

DISCUSSION.

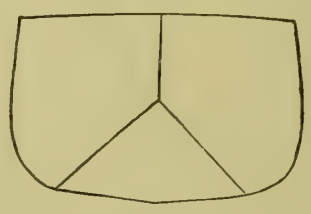
Mr. A. C. Kirk (Member of Council): My Lord and Gentlemen, it was certainly very far from my thoughts to say anything on this very admirable Paper of Mr. Martell's, which, I think, very nearly exhausts the subject. It is a young subject, and a growing subject, and experience is not yet very largely to be quoted in favour of either one plan or another. I was for six years an oil maker, but never an oil shipper, and therefore my words will be but few. About 1868, I had to report on a ship built to carry crude oil—home made oil—to Norway. That ship was a failure, partly from bad workmanship, partly from bad design. The oil was carried in a double bottom, very like an ordinary water ballast tank, but deeper, the intention being to carry ordinary cargo above it, but the construction was so faulty and, in fact, so incapable of being mended, that the idea was given up. The floor of the hold or the ceiling of the oil-tank was not properly joined to the sides, and the oil worked its

way up between the frames and the skin of the ship, and between the reverse bars of the frames, and so on. There is no difficulty whatever in making a riveted structure oil-tight. I have made many tanks, as near as I can say, up to 30 feet diameter and 15 or 16 feet deep (I do not recollect the dimensions exactly), and had no difficulty whatever. These were circular tanks. The work was simple. The rivets were $1\frac{1}{2}$ inch pitch and $\frac{5}{8}$ inch diameter, with plates from $\frac{1}{4}$ to $\frac{3}{8}$ inch. Below that the rivets were smaller, and a smaller pitch was used. When you come to more complicated structures, that required to be stayed with angle irons, then the problem is more difficult. The slightest springing of these structures will tend to start leakage, which never dries up, and I think the simple plan in the "Crusader," at present, at all events—I do not speak of future experience—would commend itself, as at once being very effective and very simple. There would be no difficulty whatever in having these tanks perfectly tight and without leakage. In the tanks I made there was no packing used in the rivet joints, the plates were simply riveted in the ordinary way with snap rivets well driven down. I think, my lord, I have said all I ought to say upon the subject.

Mr. H. F. Swan (Member): My Lord and Gentlemen, the subject of the Paper which Mr. Martell has read is certainly one of very great interest. It is a subject to which I have given very great attention and, I hope, have done a little towards advancing knowledge on the question of carrying oil in bulk. In the numerous diagrams that I see before me, I am somewhat struck with what I would call the unnecessary complication of most of them. In carrying petroleum in bulk, the great difficulties to be dealt with or contended against, are the questions of the leakage and the change of bulk of the liquid cargo by expansion and contraction, and also last, but not least, the danger which there no doubt is in oil-carrying vessels, by reason of the gases which are evolved from the cargoes. Beginning with the last objection first, it seems to me (while it is admitted that there is this great danger) that in sub-dividing vessels, there should be left so many spaces in which these gases can accumulate, it is a pity to raise up a difficulty for the purpose of having to overcome it. It is, perhaps, rather strange that the only steamer that has yet been specially built to cross the Atlantic is not represented among those diagrams, and I can explain how that arises. Some weeks ago, Mr. Martell wrote me that he was about to write a Paper on this subject, and asked for a sketch of that vessel, but unfortunately, we were precluded by the express orders of the owners from supplying information. I had hoped before this Paper was read to have been in a position to supply Mr. Martell with sufficient information, but he wrote me that he had already obtained it, and that he need not trouble me. I had supposed that he intended to make use of the published diagrams on the subject, which would at any rate have explained the matter sufficiently. Perhaps I might be allowed just to make a diagram on the board, which will show easily enough what I mean.



No. 1.



No. 2.

These two diagrams will sufficiently illustrate what I mean. The steamer "Glückauf," * which

* Since making the above remarks the "Glückauf" has completed her round voyage to New York in ballast and back in ballast, in the most satisfactory manner, and has in all respects justified the expectation that has been made regarding her. —H S.

has already been finished, and which I expect in the next day or two will arrive in New York, is built on plan No. 1. The oil is carried right out to the skin of the vessel. This vessel is built with a central bulkhead, with a large number of transverse bulkheads, which are worked in pairs. To each pair is provided an expansion trunk such as is shown, and among other advantages possessed by the vessel is this, that in case, for instance, of damage, every portion of the shell can be examined and repaired, whereas in any of these vessels which are fitted with inner tanks, in case of collision or anything in the ordinary way of repair of the ship being required, the sides are quite inaccessible. It would be impossible to imagine that vessel (pointing to a vessel fitted with separate tanks) being struck by another ship and the outer skin injured without the tank also being pierced. Then the question of insurance must be a serious one, whereas in the "Glückauf" we have to deal with a totally different condition of things, for it would be possible to imagine the ship's bottom entirely knocked out, and yet she would float and come to her port of destination without any serious casualty. The lightness of the oil itself is such that it will remain in the upper part even although damage occurs here. [Illustrating.] Only a few months ago I was speaking with a Russian gentleman who owns a vessel in which that very thing occurred. The vessel struck an anchor and had her bottom completely torn along, but notwithstanding this serious damage the loss of oil was extremely small. Then, again, there is the question of the insurance of the cargo itself. In a case of that kind, where the vessel is pierced, only one compartment is affected, and the amount of oil that could be damaged by such a casualty would be extremely small. If you imagine a ship fitted with separate tanks crossing the Atlantic, or going on a coasting voyage some distance from home, where repairs were difficult and costly, in case of a casualty happening to her, the water would immediately rush in and surround the whole space in which the tanks are situated, and the cost of taking out the tanks and disposing of that amount of oil in an "out-of-the-way" place, would be such as to be a very serious question for the underwriters. On the question of leakage a good deal has been said, but with regard to that I would entirely endorse what Mr. Kirk says, that there is not the slightest difficulty in making oil compartments perfectly tight. We have submitted the "Glückauf," which has just gone away, to exhaustive experiments on the subject. Throughout the building we treated her as a boiler, and each compartment as a boiler compartment. The result is, that when tried with a pressure double what she can ever have in ordinary practice, she was perfectly tight. It is not a question of the tanks being nearly tight, but on the trial trip, when she had several of the compartments filled to the upper deck, there was only one rivet that showed a tear. Then, as regards the question of straining to which Mr. Martell referred. This vessel is strongly braced by girders or stringers, in such a way that, coupled with the large number of transverse bulkheads that she has, I am perfectly certain she is out of all proportion stronger than any existing merchant vessel, and I would have no hesitation in seeing her placed with her keel on one point as a pivot, because I am certain that she would stand the test just the same as a girder. In carrying out the construction of the vessel very great care was taken to treat the bulkheads not as the ordinary bulkheads of a ship are treated. If you take any ordinary ship and fill her with water to her upper deck, the bulkheads would sag or bulge to a large extent, whereas in this vessel, when she was tried in this way, there was not the slightest deflection from the straight either vertically or horizontally. I must say, unless for the purpose of ballasting, I cannot see the use of a double bottom. People meet that by saying it is to keep the oil away from the bilge water. I prefer to go to the root of the matter and say, where is the bilge water to come from? If the ship is efficiently constructed, perfectly complete in all parts, where is the bilge water to come from? As long as she remains staunch and tight there is none. However, for the Atlantic trade

it is necessary to ballast the ship efficiently. Ordinary vessels are sent across the Atlantic with ballast of, say 25 per cent. of their total dead weight, and the result is that many of them suffer serious damage. This ship has gone away now laden to about three-fourths of her total dead weight, and the consequence is that she is in good trim. If it be objected that to do that she has to carry water in certain compartments that will afterwards be used for carrying petroleum, that difficulty, if it is such, can be overcome. It is not that the sea water mixing with the petroleum spoils it, but it is that the sea water penetrating between the surface, causes rust, and that rust is eaten away by the petroleum and discolours it. If the internal surfaces were treated with a proper composition they could be made so as not to corrode with the action of sea water. If that statement holds good, and the objection is not overcome in this way, I contend that it is met by making the ship's bottom in *this* form [indicating the conical form of bottom No. 2]. By doing so you gain several advantages. To immerse a vessel with an ordinary double bottom, say *that* height [indicating], and to give her the requisite amount of immersion would cause her to be too stiff, in fact, a very bad sea vessel. To meet that point, I would suggest making the double bottom in that form by which the centre of gravity is raised; and although I have heard it criticised by saying that it looks like a donkey with saddle bags, members of the Institution are sufficiently wide awake to know that that really does not hold good. Then, again, with regard to getting rid of the gases. Take any ordinary double bottom; if any petroleum gets in from leakage, the space would be filled with gas, and would be in such a condition that it would be almost dangerous to life for men to creep about there, and certainly it would be impossible to go in with a light. By adopting this form this compartment could be filled, and in case the vessel had to be repaired, all that it is necessary to do is to fill this bottom with water, and there being trunks extending to the upper deck, pumping could be continued until the gas and water overflowed over the upper deck, thereby clearing out every particle of oil and gas that was lodged there. Gentlemen, I think I have explained in general terms the features of these two systems, but no doubt we have all a great deal to learn on the subject yet.

Mr. Charles Marvin: My Lord and Gentlemen, there is no passage in this very interesting and important Paper which has excited in me a greater feeling of pleasure than the fact Mr. Martell states, that "there are not wanting signs that many of the shipowners of this country are awakening to the necessity of taking immediate steps to secure a share of that important industry which is almost entirely at this time in the hands of foreigners." I remember in 1879, when I was collecting information for a book on the advance of Russia upon India, I was very much struck with the importance of the petroleum industry at Baku, and with the efforts which Messrs. Nobel were making for conveying petroleum from Baku to the rivers in Russia by means of tank steamers, which conveyed the oil up the Russian rivers, and which were nearly all built in Sweden. The Russian press in discussing the future of that branch of industry declared that at no distant time the petroleum trade would spread from Batoum to Europe, and I urged through the press that English shipowners should take early steps to make a speciality of the construction of these tank steamers, so that when that time arrived they would be in the field, and the Swedes would not have a monopoly of that trade. How great has been the development since 1879, may be gathered from one or two statistics. I think it was in the spring of 1879, that the first tank steamer appeared on the Caspian Sea. At the present moment there are over eighty vessels there, and twenty more will arrive at Batoum before the close of the season, making 100 altogether. Besides those 100 steamers, which have been specially constructed for the trade, there are also 300 sailing vessels, many of them three-masted, which have been provided with tanks for the conveyance of astatki, benzoline, and the lighter oils. This will give you an idea of the rapid

development of the petroleum marine in the Caspian Sea, supplying only the single market of Russia. If so many vessels are required for one market, how many will be required for the markets of the world generally, now that oil is being brought in bulk from America and Russia to the various parts of Europe? We are not, indeed, wanting in prophets who predict that before five years have passed there will be 300 or 400 tank steamers running between various parts of the world, and the question is, what nation is to construct those steamers. The Swedes, thanks to the fact of Messrs. Nobel being Swedes by birth, were the first to construct these tank steamers for the Caspian trade, and owing to that circumstance they have been able during the last five years, while there has been a very severe period of depression in this country, to escape that depression in the ship-building trade, and to be continuously occupied. They have, in a word, constructed most of those 100 vessels on the Caspian Sea. I hope now that, after several years of agitation, and English shipowners have gone thoroughly into the subject, most of the vessels required for the Atlantic, the Black Sea, and the Mediterranean will be constructed in this country. I imagine, nay, I feel sure, that that is the wish of everybody present in this room this morning. The matter is an exceedingly important one for this country, because not only are we interested in the petroleum trade, owing to our position as the chief carrying nation of the world, but we also possess very large petroleum fields of our own in Burmah, India, and Egypt; and the development of those must, I feel persuaded, remove some of that depression which at this moment affects British trade in every part of the world. It is a peculiar circumstance that although there has been a remarkable expansion of the bulk system of transport in Russia, and although so many Russian Engineers have devoted their attention to the subject, Mr. Martell's Paper is the first that has been written on the subject, dealing with it technically. This, I think, must be a source of great satisfaction to every member of the Institution, and it is very gratifying to me as an Englishman, that although Sweden has been first in planning these vessels, yet the first important record of the progress of this tank steamer industry has proceeded from the pen of a member of this important Institution.

Mr. W. Laird (Member): My Lord, Mr. Martell, and Gentlemen: As one of the Reception Committee I should like to express the very great pleasure which I and others of that Committee present here have felt at hearing the Paper which has just been read. Mr. Martell has managed to put in his Paper an amount of information which is most interesting, not only because it relates to the technical details that shipbuilders and engineers have to do with, but also because it opens up a question of much wider interest to the general trading community—to those engaged in trade as merchants, and also those engaged in trade as shipowners. With regard to those who have the management here of the receiving of cargoes that are brought by shipowners, the question arises how they are to receive these cargoes of petroleum if they come in bulk. At present a very large trade in petroleum is done at this port, but it is brought principally in casks. The arrangements at present for receiving the petroleum are of a very extensive character, but it is dealt with in this way—stowed in casks. I believe that if it should come about, as fore-shadowed in this Paper, that the trade is to be at some no distant day done by bringing petroleum in bulk in ships, such as are described in Mr. Martell's Paper, the enterprise of the *Port* of Liverpool will be quite equal to the demand made upon it, and that suitable arrangements will be made to meet the changing conditions of the trade. I have had very great pleasure in listening to the Paper, and am sure that this important Institution will allow me to convey my congratulations to Mr. Martell for having made what might have been a mere technical Paper, a subject of so much wider and more general interest.

Mr. B. Martell (Member of Council): My Lord, in view of the anxiety we all feel to listen to Mr. Lyster's Paper, I will not occupy more than a few minutes of your time. With reference to Mr. Swan's remarks, I may say I am very well pleased that he was not enabled to respond to my call for the information I asked for, because he has explained the plan of the vessel which he has built, and given us the information in a manner so much fuller than I could have given it, that I think it has been a very good substitute for the description I should have given had I been supplied by him with the information applied for. Mr. Swan talks about a perfect ship which I apprehend must be the case when you can find no bilge water in it at all; as far as my experience goes they are difficult to find. How the water gets into vessels I cannot tell, but in all vessels, more or less, I know we do find water. I do not agree with Mr. Swan that refined oil would not be damaged by salt water. Gentlemen in this room who have great experience with reference to the petroleum industry, and I see here more than one, well know that with this kind of petroleum, sea water getting into a vessel would damage it very considerably; indeed, so much injury would be done to it that it would take away the profit of carrying the cargo. Therefore, it is a matter of very considerable importance. The performances of the vessel in question and the results will be looked forward to with very great interest indeed, as to whether vessels for the trade can be constructed in such a perfect manner so as to keep all water out, which somehow or other does in ordinary cargo steamers get into them. I hope it will be found so. With regard to the carrying oil in the double bottom that Mr. Swan alluded to, I would just make one remark. I may say that one of these vessels which came to this country a short time ago had one or two tanks filled with salt water for the purpose of water ballast. The effect of that was—it was found after the water had been pumped out—that the residuum at the bottom of the tank was of such a character that they had the greatest labour in getting that tank fit to carry petroleum oil again. Unless you fill the tanks with perfectly fresh water you will find it will require considerable labour to make them fit to carry this highly refined petroleum oil. I do not think I need say any more to occupy your time further than to return my very sincere thanks for the manner in which the Paper has been received.

The President: I am quite sure I shall receive your unanimous permission to present our united thanks to Mr. Martell for his very able Paper, and I hope he is satisfied with the discussion that has ensued upon it.

DESCRIPTION OF THE RIVER MERSEY AND THE PORT OF LIVERPOOL.

By George Fosbery Lyster, Esq., Associate M.I.C.E.

[Read at the Twenty-seventh Session of the Institution of Naval Architects, at Liverpool, July 27th, 1886; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The visit of this distinguished Society to the City of Liverpool has been an inducement to me to present for their consideration a description of the Mersey and its interesting surroundings, with special reference to the Dock Estate.

Although, doubtless, the peculiar physical conditions of the river, and the subjects to which I refer, are generally known, and the character and volume of the trade of Liverpool well understood by most of those present, I cannot but think that a brief and simple Paper on these points will be of some interest to a Society whose special action lies in the direction of considering and discussing such improvements in marine architecture, as will help to facilitate and economise the transit of goods by sea, river, or canal, and of this I am more assured by the knowledge that a visit to the docks and lower reaches of the river will follow its reading, so as to allow of the members examining for themselves the several points of interest to which I briefly draw attention.

Though the River Mersey plays an important part in the commerce of the world, its volume of foreign trade having been in 1881–2–3 slightly greater than that of the Thames, and largely in excess of any other port in the Kingdom; in extent, capacity and area of its drainage basin it is much below the Thames, and indeed of several other English rivers, ranking only fifth on the list, while its physical characteristics widely differ from those of most of the rivers in the British Isles, chiefly as regards its peculiarity of form, and the important consequences involved thereby.

The River Mersey first bears that name at a point in Cheshire a few miles to the east of Stockport, where it is formed by the junction of two streams, the Etherow and Goyt, which rise in the Derbyshire Hills on the borders of Yorkshire and Cheshire respectively.

The entire length of the river, from the point where it first bears the name of Mersey, to the sea is 56 miles.

The general direction of its flow for the first 37 miles, to the point where it reaches the town of Runcorn, is towards the south-west, and for that length it partakes of the form of an ordinary river of restricted size, with parallel banks, having a tortuous course, and passing through an agricultural country chiefly of the red sandstone formation. At Runcorn, where it passes through the bluffs known as Runcorn Gap, it takes a somewhat sudden bend nearly at a right angle from the direction of its upland course, and expands into an estuary from two to three miles in width, following a north-westerly direction to the sea. *See* Plate VIII.

For the last six miles of its course, along which the City of Liverpool is situate on the right bank, and the town of Birkenhead on the left, with their several systems of docks, the Mersey becomes contracted, and at its narrowest point opposite the centre of Liverpool, its width is only about 3,000 feet.

From Runcorn to the sea it will thus be seen that the river is of a form which has been aptly described as that of a bottle, of which the wide expanse between Runcorn and Liverpool forms the body, and the narrows opposite Liverpool the neck.

Having now briefly described the course of the Mersey generally, it may be of interest to refer to its more important tributaries. The first of these is the Tame, which joins the Mersey upon its right bank at Stockport; and the next, and perhaps the most important affluent is the Irwell, which rises in North Lancashire, and after a tortuous course of about 28 miles in a southerly direction, in which it receives the Roch, Irk and Medlock, it passes through Manchester and joins the Mersey at Flixton, a point eight miles below that city. Between Flixton and the important town of Warrington, the Mersey receives the waters of the Bollin and several minor streams.

The total area drained by the river to Woolston Weir, five miles above Warrington, is about 750 square miles.

Below Warrington no considerable stream joins the Mersey until the town of Runcorn is passed, a mile below which the Weaver, a very important tributary, discharges its waters into the estuary, its junction, channel, and general direction being nearly at a right angle thereto. Having its source in the southern portion of the county of Chester, the Weaver, with its tributaries, chief of which are the Dane and Wheelock, drains a great part of the centre of the county, the area of its catchment basin being about 550 square miles.

The River Gowy and other minor streams drain nearly the whole north-western peninsula of Cheshire into the Mersey estuary, which also receives on the Lancashire side below Warrington the waters of a number of small streams.

The drainage from the site of the city of Liverpool finds its way directly into the estuary, while that of the district around the city is effected chiefly by means of the small River Alt, which rises in the high ground in the neighbourhood of the village of Huyton,

and runs through the agricultural country intervening between it and the sea, which it enters from the shore of Liverpool Bay.

Being outside the mouth of the Mersey, its outflow does not affect the condition of that river, though, no doubt, it assists in proportion to its volume in forming the special configuration of the banks and channels of Liverpool Bay.

The aggregate area of the catchment basins of the rivers and streams referred to, the waters of which are discharged by the Mersey into the sea, is 1,724 square miles, and the rainfall varies in different localities within the area from 25 inches to 53 inches per annum.

The upland water discharged into the estuary, chiefly by the Mersey and Weaver, amounts to some two or three million cubic yards in twelve hours, while the volume of tidal water passing in and out from the sea at the Rock Lighthouse has been computed at 710,000,000 cubic yards on a high spring tide, and 281,000,000 cubic yards on a low neap.

Compared with these figures, the amount of the upland water appears insignificant, yet combined with the tidal ebb and flow, it has a most important influence in maintaining the normal capacity of the estuary, and counteracting the process of silting which is continuously going forward within its area.

The total tidal area of the estuary within the Rock Lighthouse is 22,500 acres, and the greater portion of this, between Runcorn and the narrows at Liverpool and Birkenhead, is filled with a deposit of sand, 17,300 acres being above the low water mark. Through this vast body of sand the upland water ploughs its way and forms channels for itself in its course to the sea.

The direction of these channels is never constant for any length of time, and by their incessant wanderings through the two or three miles width between the Lancashire and Cheshire banks, permanent accretion is prevented.

On this peculiar feature no doubt the maintenance of the Mersey as a great Tidal Estuary depends, and were any stoppage or interference with the roving tendency permitted, permanent accumulation must take place, and the growth of solid land, to the exclusion of a corresponding bulk of tidal water, would be the result. It is a generally accepted opinion that any serious exclusion of tidal water from the estuary must injuriously affect the sea channels and the Bar of the river, and finally destroy the port of Liverpool.

The Mersey enters the sea at a point where the lines of the Lancashire and Cheshire shores form a right angle with each other, the former extending in a straight line eight miles

northward to Formby Point, and the latter eight miles westward to Hilbre Island at the mouth of the River Dee.

Between these two coast lines of Liverpool Bay are situate the immense extent of sand banks which form so formidable a barrier to the entrance to the river. The area of these banks, dry at low water of a spring tide, is 23,000 acres; they take somewhat the form of a quadrant, and to a large extent fill up the area of this corner of the Bay, which but for the action of the river and tidal water, would become entirely solid from shore to shore, with its sea face in the form of any ordinary beach.

The tidal volume which twice every 24 hours passes into and out of the estuary with its bulk supplemented by the fresh water of the uplands, passes over and forces its way through the banks, thus forming channels, depressions and level plateaux. On the efficient maintenance of the channels so formed the convenient and safe access to the Port of Liverpool is entirely dependent.

The flow of water through the banks is mainly confined to one large channel, but there are also two minor channels one on either side of it, which are important in so far as they are used to a considerable extent by the coasting traffic. That on the left is called the Rock Channel, and follows the line of the Cheshire shore towards the mouth of the Dee; the other, the Formby Channel, passes through the plateau of banks on the north side of the main channel and joins the "deep" somewhat beyond Formby Point on the Lancashire shore.

The three principal channels referred to are all thoroughly well buoyed and lighted by the most improved system of buoyage, and by leading lights, floating and fixed.

The large or main channel, which is known as the Crosby Channel, for the first six miles of its length follows the Lancashire shore in a northwardly direction, it then changes its course towards the north-west, and so continues to the Bar; its navigating width as defined by the buoys, varying from half to three-quarters of a mile, and its depth from 25 ft. to 50 ft. at low water spring tides. At its outer end, where it bears the name of the Queen Channel, it terminates in a Bar, which assumes somewhat the form of a horseshoe having its convex side seawards, and over which the navigating depth is reduced to 10 ft. at low water spring tides, or 40 ft. at high water of the same tide, and at low neaps to 20 ft. and 30 ft. respectively.

Although the channels described, as well as others of a minor character not referred to, pass through frequent phases of change, it has been found that the unassisted efforts of nature have hitherto maintained them so fairly stable that the conditions of navigation remain practically uniform.

From careful observations it has been ascertained that the Bar is constantly but very gradually moving in a seaward direction, maintaining however its general form and characteristics.

The great range of tide in Liverpool Bay which insures a depth of at least 30 ft. over the Bar once every 12 hours even on the lowest neaps, which are periodically but few and far between, must be considered as affording a comparatively convenient approach for even the largest vessels; nevertheless in such days as these, when the tendency is towards a still further increase in the size of ships, and when time forms such an important factor in successful trading, it is evident that a deeper channel to such a port as Liverpool would be desirable.

The problem involved as to the best means of attaining such an end is, however, surrounded with physical and financial difficulties of no ordinary character, and though the question is prominently kept in view, no steps have been taken towards its solution.

Within the Bar ample depth of water for the largest ships is found along the Crosby Channel through the narrows at Liverpool and up to the Sloyne one mile beyond the southernmost of the Liverpool Docks. The depth at low water spring tides in mid-channel at the Rock Lighthouse is 50 ft., in the narrowest part at Seacombe 60 ft., and opposite the Southern Docks 35 ft., whence the bottom of the River slopes rapidly upward.

The tides of the Mersey have a vertical range amounting to 10 feet on the lowest neaps, while on equinoctial springs the range opposite Liverpool is as much as 31 feet.

The neap tides referred to reach Fidler's Ferry, near Warrington, a distance of 23 miles from the mouth of the river, and the volume of tidal water entering at the Rock Lighthouse on such a tide is 281,000,000 cubic yards.

The equinoctial springs ascend the river as far as Woolston Weir, five miles above Warrington Bridge, or 33 miles from the Rock Lighthouse, and the quantity of tidal water entering the river on such a tide is computed at 710,000,000 cubic yards.

In the passage of this vast volume of water through the narrows at Liverpool the velocity of the tidal current is necessarily great, being at certain times of ebb and flow as high as 7 and 7½ miles per hour.

The datum level for all engineering works in connection with the Mersey is that of the Old Dock Sill, and the spring tide referred to as having a range of 31 feet, has its high water level at George's Pier, Liverpool, 21 feet above, and its low water 10 feet below the Old Dock Sill.

The following are the heights to which that tide rises at various points in the bay and river, and the times at which high water occurs, assuming that it is high water at the Bar at 12 o'clock :—

	Time.		Height above Old Dock Sill.	
	H.	M.	FT.	IN.
At the Bar	12	00	20	0
At George's Pier	12	30	21	0
At Garston and Eastham	12	37	21	9
At Runcorn Bridge	1	25	23	6
At Fidler's Ferry	1	45	24	0
At Warrington Bridge	1	55	25	0
At Woolston Weir	2	20	23	6

From this it will be seen that when it is high water at Woolston Weir, the tide has ebbed for 2 hours 20 minutes at the bar and 1 hour 50 minutes at George's Pier.

The exact physical condition of the bay and estuary is carefully noted by frequent and elaborate examinations and surveys carried on by the Marine Surveyor of the Dock Board, Lieut. Sweny, R.N., and his official staff.

For many years this important duty was ably carried out by Captain Graham H. Hills, R.N., now retired from the service, who in his 30 years' experience of the Mersey has fully mastered its peculiar physical conditions, and is an accepted authority on all matters connected with the river. Amongst many other improvements, Captain Hills established the excellent system of uniform buoyage now in use and lately adopted by the Trinity Board.

Having dealt very shortly with some of the physical characteristics of the River Mersey from its source to the sea, before proceeding to speak more particularly of the docks and trade of Liverpool, I will briefly refer to the several canals and navigations connected with the Mersey, as also to the minor up-river ports.

Several of the most important canal systems of this country have their terminating ports on the Mersey, and are valuable factors in developing and assisting the trade of Liverpool and Birkenhead with their surrounding districts, some of them usefully competing with the numerous railways which pass through this part of the country.

The only canal which has a direct connection with the Liverpool Docks is the Leeds and Liverpool, which traverses the country to the north of Liverpool, and is in direct communication with the manufacturing and mineral centres of Lancashire and Yorkshire.

Its length is 144 miles, and at various points of its course it is connected with other navigations. At its eastern terminus at Leeds it is joined up with the Aire and Calder Navigation, and by this means through communication is secured between Liverpool and Hull as well as the other Humber ports.

Ellesmere Port, situate on the left or Cheshire bank of the Mersey, nine miles above the centre of the Liverpool Docks, is the terminus of the Shropshire Union Canals, an important system, having a length of 203 miles, and passing through many of the leading trading centres of Cheshire, Shropshire and Staffordshire, and joining up with the River Severn and the network of canals in the Midland counties.

The traffic passing through Ellesmere port is very considerable, amounting to between 300,000 and 400,000 tons per annum; vessels up to 400 tons making use of the docks.

The Weaver is an important navigation working into the Mersey and interchanging a large trade with Liverpool, from which its terminal docks at Weston Point, on the left bank of the Mersey, are distant 14 miles.

This navigation is in the form of an ordinary canal for the first four miles of its course, after which it is joined up and incorporated with the River Weaver itself, which has been canalized and made navigable for comparatively large vessels.

The staple product of the Weaver Valley is salt, procured from the mines and pits in the vicinity of the towns of Northwich and Winsford. The steam lighters employed in the trade have a capacity of 300 tons, the depth of the navigation being 10 feet as far as Northwich, and above that point 9½ feet to Winsford, the end of the navigation, the total length of which is 22 miles.

At Northwich a connection between the Weaver and the Trent and Mersey Canal is effected by the Anderton Hydraulic lift, a special arrangement for transferring barges from one navigation to the other, the difference in level between them at this point being 50 feet. By this means the Weaver communicates with the waterways of the Midlands.

The salt trade from the Weaver amounts to 1,000,000 tons annually, of which 800,000 tons go to Liverpool.

The remaining waterways in connection with the Mersey are the Bridgewater Canal and Mersey and Irwell Navigation in Cheshire, together forming one system; also the Sankey Canal in Lancashire.

The Bridgewater Canal was constructed about 120 years ago for the celebrated Duke of Bridgewater, by his equally celebrated Engineer Brindley.

Its terminating docks are below the bridge at Runcorn, adjoining those at Weston Point belonging to the Weaver Navigation Company, with which they are connected. They are of considerable extent and are capable of admitting large coasters.

This canal passes chiefly through an agricultural country to Manchester, where it joins the several canals from the surrounding district converging to this important centre.

About one mile below the City of Manchester an important branch leaves the main canal and takes a northerly direction, crossing the Mersey and having its terminus at Wigan, where it joins up with the Leeds and Liverpool.

On the south side of the Mersey, to the east of Runcorn, the Brigewater system is joined up with the Trent and Mersey Canal, thus incorporating it with the great central waterways of the Midlands.

The total length of the Bridgewater system is about 40 miles. The traffic passing over it in connection with the Mersey amounts to the large total of one-and-a-half million tons per annum, and its inland connections increase this amount by another three-quarters of a million tons.

The Mersey and Irwell Navigation, also belonging to the Bridgewater Company, commences with a group of small docks opening upon the Mersey at Runcorn above the bridge, thence extending in a canal form towards Warrington, near which it becomes incorporated with the Rivers Mersey and Irwell, and so continues to Manchester, these rivers being partially canalized to serve the purposes of the navigation, having only been constructed for small light craft, however, it has fallen into partial disuse.

The Sankey Canal completes the water-ways in direct communication with the Mersey. It commences with a small dock opening upon the river at Widnes, and continues in nearly a straight line, extending along its right bank to a point about one mile below Warrington; thence it turns in a northerly direction towards the town of St. Helen's, where it terminates.

The only other ports on the Mersey in addition to the small groups of docks which form the termini of the several canal systems referred to, are those of Garston, Widnes, Warrington and Frodsham, the latter two, however, being of so limited a character as to need no other description than that on certain favourable conditions of tide small river craft can reach the wharves in their vicinities.

The town of Widnes has of late years acquired a small dock, and seems to be developing considerable shipping trade, chiefly in chemicals, with coasters and light craft of that character.

Garston, situate on the Lancashire shore, about three miles above the southern termination of the Liverpool Dock Estate, is a port of considerable importance, with a fairly good approach channel, but of a varying character. The docks are in direct communication with the London and North-Western Railway, to which Company they belong. They

are two in number, of a gross area of 14½ acres, surrounded with coal staiths and appliances of a modern character.

The trade of Garston, which is chiefly in coal and minerals, amounts to about two million tons per annum.

Although I have found it necessary to reduce my remarks as to the physical conditions of the Mersey to the briefest possible proportions, and deal with them in the merest outline, I feel I have already somewhat trenched upon the time limits allowed for a Paper of this description, and must therefore be correspondingly short and sketchy in my notice of the docks, as were I to attempt an elaboration of the many interesting features connected with this important estate, the time of the Association would be unduly occupied to the detriment of the personal and more instructive examination of the works which I hope its members will be able to undertake.

As far back as 1550 Liverpool seems to have occupied a somewhat important position in whatever maritime trade existed on the Western seaboard of the country, and the port was then regarded as one of the best natural harbours along this coast. Even at that early date it is recorded that a public officer was appointed by the local authorities to guard its interests, and some sort of artificial shelter seems to have been provided for the protection of the small craft which traded to the adjoining districts and Ireland. Unfortunately it is impossible to define its condition at that time, as no maps or plans of the period are in existence.

From such local records, however, as do exist, meagre as they are, it is evident considerable energy and foresight was displayed in providing improvements from time to time to secure the safety and convenience of the vessels which traded to the port. These were few in number and small in size, it being recorded that 15 vessels with a gross burthen of 268 tons, represented the extent of the shipping which traded to the Mersey in 1565.

The site of the original port was that of the shallow creek which ran inland from the right bank of the river in a north-easterly direction, its length was about a mile, and judging from its position it must have been well sheltered from the action of the prevailing winds. It is evident that vessels must have loaded and discharged their cargoes, in fine weather, either by means of boats in the river or by grounding on the banks of the creek, making use of carts at low water as is now done in minor ports along the seaboard of the country.

Owing to the rapid development of manufactures in the north-western counties of England, it became evident in the early part of the last century that the time had arrived when steps should be taken in the direction of providing improved accommodation for the

enlarged class of vessels which dealt with the exports and imports of the country, and which made Liverpool their port of arrival and departure.

When this important epoch in history arrived there were not wanting men of energy and enterprise to face the problem, and those pioneers of progress had the distinguished honour of devising and constructing the first wet dock that ever was built in England, thus setting an example to those important ports which have since grown into existence and have helped to bring the trade of the kingdom to its present unexampled condition of greatness.

In the year 1708, in the reign of Queen Anne, Parliamentary authority was obtained for the construction of a wet dock at the entrance of the pool of Liverpool. It was to cover four acres, and to afford accommodation for 100 vessels, and was arranged to have not less than 14 feet of water within it on low neap tides with a sufficiency on springs to accommodate the smaller ships of war.

This dock was designed and carried out by Mr. Thomas Steers, a prominent engineer of the period, whose family are connected with Liverpool to this day. Since then the port of Liverpool has steadily progressed.

The old dock has long since passed away—its site is now occupied by the Custom House—and the surrounding district is covered with houses, warehouses and shops, no sign of the old pool being noticeable, though its previous existence may be inferred from the depression of the street surfaces along the line of its course.

It was long thought that the filling up of the dock and the utilization of its area in the manner described was a grave mistake on the part of the authorities, but such an opinion cannot be sustained with any show of soundness, as the constant severance of the city by perpetuating the dock must have ultimately proved an intolerable nuisance and been destructive to the convenient working of this important district of the town.

The site for the extension and development of the existing dock system on the Liverpool side has been wisely chosen along the margin of the river, abutting for most of its length upon the deep water of the channel. Here for a length of over six miles and for a width varying from 700 to 2,200 feet the foreshore between high and low water has for the most part been enclosed from tidal influence by the construction of a continuous sea wall, except where apertures were required to form entrances into the range of docks behind it.

The earlier docks commenced abreast of the old dock, and extended towards north and south, including the Salthouse, George's and Prince's group, Plate IX., all remaining to this day (some without alteration) and testifying to the foresight and ability with which they were designed and carried out by Mr. John Foster and his son, who were then the surveyors to the Corporation, by whom the affairs of the docks were administered.

In the year 1824 Mr. Jesse Hartley became the surveyor and engineer to the estate, and designed and carried out those vast ranges of docks, with their surroundings, between the Waterloo and the Canada in a northerly direction, and the Canning, Albert, Wapping, Coburg and Brunswick, with other minor groups towards the south—in fact, to his genius and practical knowledge, during the 36 years he occupied the position of engineer to the estate, Liverpool undoubtedly owes much of her commercial greatness; these vast undertakings having established the port as the greatest in the world.

Mr. Hartley died in 1860, full of years and honoured and respected by all who knew him, or who were acquainted with his great career and force of character.

During the latter period of his life he was ably assisted by his son Mr. John Bernard Hartley, who at his father's death was appointed engineer to the estate, but who owing to broken health was obliged to retire from the profession of which he was so prominent and valuable a member; the author of this Paper was then (in 1861) appointed Engineer to the Estate and has so continued since.

The Act of 1708, which has been already referred to, was the first of a long series of Acts of Parliament which have been obtained from time to time, authorizing the acquisition of lands and foreshore, and providing for the construction of the minor groups of docks already referred to and others, and also defining the mode of government of the Dock Estate.

The last important Works Act was that obtained in 1873, at which time owing to the rapid increase in the size and tonnage of steam ships, it had become necessary that special dock provision should be made to meet the requirements of the port in that direction.

Very comprehensive systems of Docks were then designed to meet these pressing wants, and Parliamentary powers were obtained to carry out the necessary works, which consisted of the development of the northern and southern ends of the Estate, previously acquired and re-claimed from the foreshore for the purpose.

The Parliamentary estimate for these schemes was £4,100,000.

The northern development, known as the North End Scheme, comprised the extension of the Canada Basin and the lowering of the level of its floor, the formation of the Langton Half-Tide Dock or entering vestibule into the main group, Two Graving Docks, the Langton Branch Dock, the Alexandra Dock and its three branches, and the Hornby Dock.

The total area of the Wet Docks provided by this extension is 83 acres, and quayage 23,700 feet, while the length of floor of the two Langton Graving Docks is 1,900 feet.

This system in common with that at the south end, presently to be described, possesses the special advantage of having all its sills laid at a very low level, being 4 feet below that

of any other sills on the Liverpool side, and this feature has been found of inestimable value for the convenient and economical working of the largest class of steam ships trading to the port.

In order to maintain the desideratum of deep water in connection with the Docks, which has hitherto been a difficulty in this locality, owing to the fact of its being on the weather shore of the river, the waters of which carry a large amount of silt and sand in suspension, a special arrangement of sluices of a very extensive character was designed. These are carried round the pierheads and entrances and are also continued along piers projecting into the river, by which means it was considered that the approaches could be entirely kept clear of sandy accumulation, and experience of the works has fully demonstrated their success.

The Parliamentary estimate for the whole of the works comprised in the North End Scheme amounted to £2,691,360, within which sum they have been carried out to completion.

The greater part of the additional dock accommodation in this position was completed in 1881, and was opened for use by their Royal Highnesses the Prince and Princess of Wales on the 8th September of that year.

The works at the south end of the Dock Estate authorised by the Act of 1873, comprised the enlargement of the Herculaneum Dock, which had been built in 1868 with a special view to future extension, and the formation of a chain of docks to the northward terminating at the Brunswick Dock, and forming a complete development of the whole of the available Estate in this position.

The sills of the main entrances and passages are laid at the same level as those of the North End Scheme, and their maintenance is effected by an arrangement of sluices and piers similar to those which have there been found to work so satisfactorily.

The gross water area added to the Estate in this position is 28 acres, with a quayage equal to 11,300 lineal feet.

The Herculaneum Dock has three large graving docks on its south side, the aggregate length of their floors being 2,280 feet.

The Herculaneum Dock and Graving Docks, and the Harrington Dock immediately to the north of the same, are finished and in full use, and the remaining docks of the group are rapidly approaching completion.

The Parliamentary estimate for the South End Scheme was £1,408,640, within which it will be carried out.

In addition to the value accruing to the trade of the port by such a large and extensive increase of docks in a district of the City hitherto unprovided with this class of accommo-

dation, it will have the further advantage of bringing some of the older docks into more prominent use than hitherto. I allude to that important group including the Brunswick and other Docks immediately to the north of it, the entrances to which are impeded by the Pluckington Bank, which extends for over a mile in length immediately in front of that portion of the Estate, and forms a serious obstruction to its free working. The New South End group will to a great extent neutralise this inconvenience by admitting vessels to enter the old dock through the new group by way of the river entrances at the Herculaneum.

The total water area of the new docks at the north and south ends of the Estate constructed under the Act of 1873 is 111 acres, equal to nearly half the acreage of the docks in existence previous to the date referred to.

The total area of the existing Dock Estate at Liverpool is 1,078 acres, and the entire of this space is developed into basins, docks, quays and premises worked in connection therewith.

There are in all at Liverpool 60 docks and basins of the ordinary type, having a total water area of 368 acres, and 25 miles of quay berthing.

The City of Liverpool has steadily followed the development of the Dock Estate, flanking it with a wide street throughout its entire length; upon this thoroughfare the side streets from the city abut, so as to afford direct intercommunication between town and docks; and this system has been followed beyond the city boundary and abreast of the New North Docks, the construction of which has resulted in a rapid augmentation of the population and importance of Bootle, a borough the charter for which dates from 1868.

The Estate is traversed from end to end by double lines of railway, communicating where necessary with the dock quays and joined up with the several railway systems that have their termini on the marginal thoroughfare which has been described as bordering the Estate. In its range of six miles there are sixteen extensive goods stations working in connection with the docks. These belong to the great railway systems of the country, viz.:—The London and North-Western Cheshire Lines, the Midland, Great Northern, Manchester Sheffield and Lincolnshire, Lancashire and Yorkshire, and Great Western; the last named of which though having no direct rail access to Liverpool, has one or two important depôts for interchanging its traffic with its fully-developed Birkenhead system.

It now remains for me briefly to refer to the Birkenhead Estate.

In 1855 the dock authorities of that day made application to Parliament for powers to extend the dock system on the Liverpool side of the river to a point further north than it then existed, this was only partially acceded to by Parliament, and in lieu of the complete proposal it was arranged that the Birkenhead Docks, which belonged to an independent

Company at that time, and were only partially developed, should be purchased by the Dock Board and finished, and brought into use for the general purposes of the trade of the port. This system, therefore, now forms an integral portion of the Liverpool Estate, and is worked in complete unison therewith.

The docks of which it consists are constructed on the site of a tidal creek called Wallasey Pool, which extended inland from the left bank of the river for about two miles, and which was formerly the outlet of the drainage of the low lands of the Leasowes lying between the Dee and the Mersey.

The original design for the undertaking was by the well-known and eminent Engineer the late Mr. James Meadows Rendel, F.R.S., who partially carried out the work. When in the hands of the projectors it mainly consisted of two large docks called the East and West Float with an aggregate area of about 120 acres occupying a large proportion of the pool.

Considerable alterations however were made in the design by the late Mr. John Bernard Hartley when the docks became the property of the Board, though the East and West Floats, and also a great low water basin and river entrances leading into smaller docks, still formed the leading features of his scheme.

The connection between the docks and river is by means of an extensive chain of docks, also a capacious half-tide dock with several locks, the sills of which are laid at a similar depth to those described for the Liverpool North End Scheme, and maintained by an extensive sluicing arrangement of a somewhat similar character.

It was the experience gained by the construction of the Birkenhead sills at this low depth that indicated the possibility of procuring a similar advantage for the docks on the Liverpool side, though at the same time it was generally considered an operation of doubtful, if not hazardous attainment.

An important feature connected with the Birkenhead system, and one which formed part of the original design, at the time causing considerable discussion in Parliament as to its merits, was that of the Great Low Water Basin. This was in the form of three sides of a large dock 350 feet in width, the open end abutting on the river, from which it extended back at a right angle for a length of 1,720 feet, and terminated abreast of the Great Float with which it was joined by means of a lock.

The basin itself was incorporated with the "deep" of the river, and was excavated to a depth of 11 feet below low-water mark, thus giving a deep water approach at the lowest tides.

The object of this work was to admit of coasters of moderate draft entering or leaving it at all conditions of tide, even at extreme low water, and thus to enable them

to carry on an uninterrupted interchange of traffic with the London and North-Western and Great Western Railway systems which had obtained Parliamentary sanction to establish goods stations on lands adjoining and belonging to the Dock Board. This was to be effected by means of a great floating landing stage established and attached to the southern quay of the basin adjoining the stations.

The work was carried out in conformity with the plans, which however differed considerably from those of the original design.

After two or three years' experience of its working, it was found to be so costly and inconvenient that its use as a low water basin had to be abandoned, and it has since been altered into the form of a dock of the ordinary type.

The total area of docks at Birkenhead is 164½ acres, with 9½ miles of quayage.

There are also three graving docks at Birkenhead, opening from the West Float and capable of dealing with the largest class of vessels, their aggregate length being 2,430 feet.

The several quays of the Birkenhead Docks are surrounded by railways which are connected with the London and North-Western, Great Western, and Cheshire Lines systems, each of which have large stations upon the dock quays.

On the acquisition by the Dock Board of the Birkenhead Estate it became necessary to establish a means of interchanging the traffic between the two estates, and with this object in view extensive landing stages were established by the Board on both sides of the river, alongside of which vessels of considerable size lie, on the lowest state of the tide.

These stages are in communication with the quays of the river wall by means of hinged girder bridges for foot passengers and pontoon roadways for wheel traffic. The length of the Liverpool stage is 2,060 feet by a minimum width of 80 feet, and that at Woodside on the Cheshire bank of the river is 800 feet long and 80 feet wide. The passenger boats which ply between the several Ferry stations on the river make use of these stages free of charge, and it is computed that no less than 22 million passengers annually cross to and fro.

In addition to the accommodation thus afforded for communication between Liverpool and Birkenhead, an important work has lately been completed by an independent Company in the construction of a tunnel under the bed of the river, which has largely increased the facilities for passenger traffic, but which is not at present connected up to the dock lines of railway on either side so as to be available for goods traffic.

The quays of the docks at Liverpool and Birkenhead are provided very completely with sheds and appliances, suitable for loading and discharging vessels with all convenience and dispatch.

The sheds in connection with the newer docks more especially are of a very commodious description occupying generally a width of quay of 100 feet. The total area of sheds on the quays of the docks at Liverpool and Birkenhead is 104½ acres exclusive of the warehouses.

At all important entrances and passages, the machinery of the gates and bridges is worked by hydraulic power, which is also used to a very large extent in connection with capstans, cranes, and other machinery.

The new north end deep water docks at Liverpool have become the centre of the great transatlantic steam trade, the older or less roomy docks are in use by coasting and sailing vessels, and at the south end several important lines of steamers have their berths.

Besides the large accommodation provided for trade generally, at certain points of the dock system, special provision is made for special trades.

Very extensive blocks of warehouses were erected about twenty years ago for the accommodation of the grain trade at the Waterloo Dock, Liverpool, and the Great Float, Birkenhead. The aggregate floor area of both sets of warehouses is 23 acres, and they are equipped with elaborate machinery for facilitating the rapid discharge of ships, and for housing and delivering the grain into railway wagons, carts or lighters.

A main feature is the transfer of grain on bands, an arrangement which at the time these warehouses were erected was entirely novel, but which has since become the recognised means of transmitting grain not only in warehouses, but from ship to quay and in other situations.

Other extensive warehouses for ordinary goods, also a special warehouse for the storage and manipulation of tobacco, in which there is a very large trade, have been erected in various positions along the estate. The total floor area of the warehouses on the Dock Estate amounts to 93 acres.

The coal trade of the port is provided for at the Bramley-Moore and Wellington Docks, Liverpool, and at the Great Float, Birkenhead. At the former position an extensive arrangement of coal sidings has been provided at a level above that of the dock quays and having connection over the streets with the Lancashire and Yorkshire Railway which is in direct communication with the Lancashire coalfields. This arrangement gives great facilities for this class of trade, as is evidenced by the fact that above 600,000 tons of coal are here annually dealt with.

On the south quay of the Great Float, Birkenhead, an extensive group of sidings and coal hoists, working in connection with the coalfields in North and South Wales, have been constructed and add materially to the trade of these docks, an average of over 1½ million

tons of coal being annually brought into Birkenhead for export, and for the use of the steamships.

The timber trade has its chief centre in the Canada and Brocklebank Docks, on the quays of which extensive yards are in the occupation of the trade.

The import of live cattle from abroad is a trade which has of late years assumed large proportions, and very extensive lairages, together with the necessary slaughter-houses and other adjuncts, have been provided both at Liverpool and Birkenhead. The area appropriated to this purpose at Liverpool is two acres, and at Birkenhead 16 acres. The northern part of the Woodside Stage, and the whole of the Wallasey Stage 350 × 70 feet are made use of for landing cattle, heavy boats being able to come alongside at all states of the tide.

The petroleum trade becomes more and more important, and in laying out the quays of the southernmost dock (the Herculaneum), very secure petroleum stores were provided by excavations in the face of the rock on the east side of the dock. These stores and others on the north quay of the Great Float Birkenhead are now in full working order.

It is scarcely necessary in a Paper of this description to enter upon the methods of carrying on the every day business of the Estate, or the maintenance of the works, beyond remarking that as a consequence of the physical conditions which have been referred to, the removal of the deposits of silt, from the large area of the docks, is a work involving considerable cost and requiring constant attention.

Dredgers of different descriptions are employed for the work, and for the last 12 years the great bulk of the dredged material amounting to over a million cubic yards per annum, has been taken out to sea by means of steam Hopper barges from 300 to 800 tons capacity of which the Dock Board now possess nine.

The gross total area of the estate on both sides of the river amounts to 1,583¾ acres. This is sub-divided into 532¾ acres of water space in the form of docks, half-tide docks and basins which are surrounded by 34 miles of quays, also sheds and warehouses having an aggregate floor area of 181½ acres, the remainder being laid out in streets and open quays, also in timber yards, shipbuilding yards, and other business premises necessary for the working of the port, with a small residue of partly undeveloped land.

The total graving dock accommodation is comprised in 24 docks with an aggregate length of floor of 14,920 feet.

The total number of ships which entered the port and paid tonnage rates in the year

ending 1st July, 1885, was 21,529, having a net tonnage of 8,571,454 tons. In this figure the capacity in or out only is represented, not both.

The total revenue of the Estate received from all sources during the same period was about 1½ millions sterling.

The affairs of the Dock Trust are administered by a body named the Mersey Docks and Harbour Board, with a number of members fixed by Act of Parliament at 28, 24 of whom are elected by the dock ratepayers, the remaining four being nominee members appointed by the Government.

The Board meet once a week to consider the affairs of the Trust, and to receive the Reports and recommendations of its several Committees (eight in all).

Special Commissioners are appointed under the Authority of Parliament to guard the interests of the river, or as the Act describes "to preserve the navigation of the Mersey from Warrington and Frodsham Bridges to the sea."

This important body consists of the First Lord of the Admiralty, the Chancellor of the Duchy of Lancaster and the President of the Board of Trade, who are represented by an "Acting Conservator." That position is now and has been for some years past ably filled by Vice-Admiral Spratt, C.B., F.R.S., etc.

The figures and facts to which I have now shortly referred will convey some idea of the extent of the accommodation provided for the trade of the port, and of its rapid development in recent times. It will be apparent that in the advance of commerce generally, Liverpool has fully maintained its place, and though it has not participated to the same extent as some other places in the extraordinary progress made by shipbuilding and marine engineering in the last quarter of a century, yet these trades in which your Association is more particularly interested, still form a considerable industry here and in variety and excellence of the work turned out, the Mersey stands second to no other port in the Kingdom.

During the first part of this century Liverpool held a foremost place in shipbuilding, its close connection with the ship-owning interest, the convenient situation of the yards, and their proximity to the docks, telling largely in its favour. Successive extensions of the docks absorbed most of the land available for the trade, and to this cause no doubt to some extent the subsequent falling off in the tonnage built as compared with other ports may be attributed.

Liverpool was not backward in the adoption of iron for the construction of ships—on the contrary, when the change from wood to iron as a material for construction was still open

to doubt, the enterprise of some of the local shipowners and shipbuilders was pushing this change beyond a merely experimental stage.

As early as 1832 there was built a small iron steamer, named the "Alburka," for an expedition up the River Niger. She was designed under the directions of the late Mr. Macgregor Laird, one of the promoters of that expedition, and left Liverpool in July, 1832, making the passage safely, partly under sail and partly steam, to the mouth of the River Niger, where she afterwards did good service. Her dimensions were 70 by 14, and her engines of 16 H.P. driving paddle wheels.

It was just about this period that the late Mr. William Laird and his son, Mr. John Laird, succeeded in inducing some of the pioneers of the present fleets of steam vessels to adopt iron instead of wood for the construction of the hulls.

Among others the City of Dublin Steam Packet Company ordered the "Lady Lansdowne" in 1833, and the "Garryowen" in 1834, and by the year 1840 Messrs. Laird had constructed some 30 vessels of iron for service in various home and foreign trades.

In 1835 two iron steamers were sent out to the Euphrates, and shortly afterwards two for the navigation of the Indus for the Hon. the East India Company, and some for the Nile, which steamed from Liverpool to Alexandria, and a small screw steamer for New York, which crossed the Atlantic under sail.

In 1837 Mr. Laird built, for the General Steam Navigation Company of London, the "Rainbow;" this vessel was of 600 tons burthen, with engines of 180 H.P., and had a high rate of speed.

At this time the mail service was done principally by vessels built under the direction of the Admiralty, and they were induced in 1840 to give iron a trial against wood, and Mr. Laird built the "Dover" of iron, to compete with the "Widgeon" of wood, a competition which proved to be altogether in favour of the iron vessel.

In the same year the gunboats, "Soudan," "Albert," and "Wilberforce" were built, followed in 1842 by the "Guadaloupe" for the Mexican Government, and in 1843 by the paddle frigate "Birkenhead," of 1,400 tons and 560 H.P. for Her Majesty's Government.

Mr. Laird also built for the East India Company several vessels, showing the advantage of light draught iron vessels carrying heavy armament. With two of them, the "Nemesis" and "Phlegethon," having a draught of only 5 feet, the interesting experiment of rounding the Cape in the voyage to India was made; others of the same class were sent out in pieces and put together at Bombay.

It is not within the scope of my Paper to trace fully the history of this branch of industry, but the visit of the Institution of Naval Architects to this place is an excuse for showing that some of the earliest specimens of iron steam vessels first floated on the Mersey, and thence proceeded to many distant stations in nearly every quarter of the globe, and the first iron vessels used in India, China, the United States, and the great African rivers were sent from Mr. Laird's Yard at Birkenhead.

The shipbuilding yards on the Liverpool side of the river are situate within the area of the Dock Estate, and abut upon the margin of the Pluckington Bank, they are in the hands of three well-known firms, who have the highest reputation for first-class work, viz.:—Messrs. R. and J. Evans & Co., Messrs. W. H. Potter & Son, and Messrs. Thomas Royden & Sons.

The extensive shipbuilding yards and graving docks belonging to Messrs. Laird, to whose early shipbuilding in iron I have referred, are situate on the Cheshire or Birkenhead side of the river, and are provided with all machinery and appliances necessary for the heaviest class of work. Here some of the largest and finest of our war-ships have been built, and an immense amount of work of a like character has been carried out for Foreign Governments, as well as for private individuals.

The average tonnage turned out from the shipbuilding yards on the Mersey for the five years ending 1884, was about 42,000 tons, 11,000 tons being from the yard of Messrs. Laird.

In addition to the building yards occupied by Messrs. Laird's firm, there is an important group of three graving docks adjoining their system, belonging to the Corporation of Liverpool, and now in the occupation of Messrs. Clover, Clayton & Co. Here a large amount of useful work in repairing is constantly carried on.

The Dock Board have also on their Birkenhead Estate a very fine group of building yards specially designed and laid out for an extensive shipbuilding trade; they have, however, only come into partial use, chiefly owing to the depression which has existed in the trade of late years.

Though the Mersey does not stand first as a shipbuilding centre, there can be no doubt that the means and appliances within the Dock Estate for the repairs and overhaul of ships of every class are far beyond those of any other port in the world, and very extensive engineering establishments are in constant work in connection with them, amongst others the well-known firms of Fawcett, Preston & Co., George Forrester & Co., James Jack & Co., Rollo & Co., the Mersey Steel and Iron Co., Brassey & Co., James Taylor & Co., Laird, Clay and Inman, and others, who each contribute their valuable aid towards the welfare of the port, and who are the means of employing large numbers of mechanics and shipwrights of a specially excellent and expert class.

The total number of graving docks belonging to the Board is 24, ranging from a length of 277 to 950 feet, with an aggregate of 15,000 lineal feet of floor; they are, for the most part, capable of admitting the largest class of ships, and are provided with every modern convenience and appliance. The cranes on the Estate range from 100 tons power downward.

An important work of a novel character, to which I may refer, has recently been carried out in connection with the extensive group of six Graving Docks branching out of the Sandon Dock. The sill of the dock is laid at a level considerably lower than those of the Graving Docks, which, though no doubt affording sufficient depth of water for the passage of the vessels of the period when they were constructed, are, on neap tides, inconveniently shallow for the large class of ships now trading to the port. In order to minimize this inconvenience, special pumps have been provided capable of delivering a large volume of water from the river into the Sandon Dock, so that on a vessel being passed over the comparatively low sill of that dock, the gates may be closed and the water raised within the dock and Graving Dock to any extent necessary to pass the vessel over the higher sill of the latter.

The machinery consists of four powerful direct-acting centrifugal pumps, made by Messrs. J. and H. Gwynne, of Hammersmith Engine Works, London. These pumps have suction pipes 36 inches diameter, drawing water from the river at the Sandon Basin, and delivering the same into the Sandon Dock. On an official trial they have been proved capable of raising the level of the water in the Sandon Dock, 10 acres in extent, by 5 feet in $1\frac{1}{2}$ hours, the water in the river falling meanwhile according to the time of the day.

Since the installation of this pumping system, it has been frequently used in connection with the docking and undocking of large Transatlantic steamers, and has proved of very great convenience to the trade of the port.

I append a tabular statement setting forth in detail the areas and general dimensions of the several docks and graving docks of the Estate, also a small chart of the river with enlarged plans of the Bay and the Docks, which may be found useful for reference.

TABULAR STATEMENT

SHEWING THE WATER AREA, QUAY SPACE, WIDTH OF ENTRANCE, AND DEPTH OF SILL FOR EACH OF THE LIVERPOOL AND BIRKENHEAD DOCKS, WITH PARTICULARS OF GRAVING DOCKS, OPEN BASINS, LANDING STAGES AND GRIDIRONS.

JANUARY, 1886.

☞ *The Old Dock Sill is the Datum to which all Levels refer, and is preserved on a Tide Gauge at the West Side of the Centre Pier of the Entrances to the Canning Half-Tide Dock.*

The Old Dock contained an Area of 3 acres 1890 yards, and 557 lineal yards of Quay Space.
Its Passage ,, ,, ,, 675 ,, 90 ,, ,, ,,

LIVERPOOL DOCKS.

LIVERPOOL DOCKS.	Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Dtm.		Water Area.		Lineal Quayage.	
		Ft.	In.	Ft.	In.	Ft.	In.	Ac.	Yds.	Miles.	Yds.
Hornby Dock	South	50	0	12	0	27	0	16	3769	0	1430
Hornby Branch Dock	South	50	0	O.D.S.		27	0	0	3354	0	308
Alexandra Dock	S. East	60	0	12	0	27	0	17	4055	0	1085
	S. West	60	0	12	0	27	0				
Alexandra Branch Dock, No. 3	...	...		...	...	...	...	7	3420	0	846
Alexandra Branch Dock, No. 2	...	...		...	...	...	...	9	2657	0	1024
Alexandra Branch Dock, No. 1	...	...		...	...	...	...	9	573	0	983
Langton Dock	South	50	0	9	0	27	0	18	589	0	1322
Do. Lock (238 ft. long)	West	65	0	12	0	30	0	0	1719	0	160
Do. do. (119 ft. long)	East	65	0	12	0	30	0	0	860	0	81
Langton Branch Dock	West	60	0	12	0	27	0	2	4549	0	671
Brocklebank Dock	West	60	0	7	9	28	0	11	1010	0	1002
	South	80	0	7	9	28	0				
Do. (Lock 110 feet long)	N. West	32	0	6	0	28	0				
	S. West	20	0	6	0	28	0				
North Carriers' Dock	West	40	0	6	0	27	0	2	3423	0	641
South Carriers' Dock	West	40	0	6	0	27	0	1	4515	0	615
Canada Lock (498 ft. long)		100	0	7	9	28	0	1	3479	0	487
Canada Dock	S. East	50	0	6	6	29	0	17	4043	0	1272
	S. West	80	0	6	6	29	0				
Huskisson Dock	...	...		...	...	...	...	14	3451	0	939
Huskisson Branch Dock (No. 2)	..	...		...	...	...	...	8	780	0	890
Huskisson Branch Dock (No. 1)	...	...		...	...	...	...	7	592	0	910
Huskisson Lock (338 ft. long)	East	80	0	6	6	26	0	0	4682	0	342
Do.	West	45	0	6	0	26	0	0	3650	0	330
Sandon Dock	West	70	0	6	6	30	11	10	100	0	867
Wellington Half-Tide Dock	East	70	0	6	9	30	9	3	813	0	400
	West	50	0	6	6	28	0				
Wellington Dock	West	70	0	6	6	31	0	7	4120	0	820
Bramley-Moore Dock	North	60	0	6	0	26	0	9	3106	0	935
	South	60	0	6	0	26	0				
Nelson Dock	South	60	0	6	6	26	0	7	4786	0	803
Canal Basin, let to Bridgewater Navigation Company	Passage	18	0	O.D.S.		26	0	0	920	0	110
Stanley Lock	West	18	0	Above 2	6	29	0	...	...	...	...
Collingwood Lock	West	18	0	2	6	26	0	...	...	...	...
Salisbury Lock	West	18	0	...	...	26	0	...	...	...	...
	Inner Sill.			2	6	...	...	...	...	...	...
	Outer Sill.			Below 5	0	...	...	...	...	...	...
Stanley Dock	West	51	0	5	8	29	0	7	120	0	753
Collingwood Dock	West	60	0	6	9	26	0	5	244	0	553
Carried forward								201	1619	11	1219

LIVERPOOL DOCKS—*continued.*

LIVERPOOL DOCKS.	Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins above Dtm.		Water Area.		Lineal Quayage.	
		Ft.	In.	Ft.	In.	Ft.	In.	Ac.	Yds.	Miles.	Yds.
Brought forward .		...	...	...	...	...	...	201	1619	11	1219
Salisbury Dock	West North	60	0	6	11	26	0	3	2146	0	406
	South	50	0	6	11	26	0	...	...	...	...
Clarence Graving Dock Basin . . .	North	45	0	4	9	26	0	1	1056	0	291
	South	44	6	4	6	26	6				
Clarence Half-Tide Dock	West	50	0	5	0	26	8	4	1794	0	635
Clarence Dock	West	47	0	3	2	26	0	6	273	0	914
Trafalgar Lock	North	45	0	6	7	23	10	0	2937	0	256
Trafalgar Dock	North	44	3	6	7	21	11	5	4546	0	764
Victoria Dock	North	45	0	4	11	21	11	5	3559	0	755
	South	50	0	6	6	26	0				
West Waterloo Dock	South	60	0	8	0	22	1	3	2146	0	533
East do. do.	South	60	0	8	0	22	1	2	3375	0	506
Prince's Half-Tide Dock	West North	65	0	8	0	31	0	4	3250	0	429
Do. do. Lock (110 ft. long) .	Middle	32	0	8	0	31	0				
	South	65	0	8	0	31	0				
Prince's Dock	North	45	0	5	11	27	5	11	1490	0	1178
George's Dock	...	...		...	...	...	...	5	154	0	645
George's Dock Passage	North	36	0	4	6	24	5	0	2439	0	356
	South	40	3								
Manchester Dock	West	32	10	Above 0	3	23	3	1	595	0	339
Manchester Lock (86 ft. long) . . .	West	33	8	Below 3	9	24	3	0	315	0	57
Canning Dock	West	45	0	6	1	26	2	4	376	0	585
Canning Half-Tide Dock	West North	45	0	6	3	28	3	2	2688	0	429
	South	45	0	6	3	28	3				
Albert Dock	North	45	0	6	4	26	0	7	3542	0	885
	East	45	0	6	0	26	0				
Salthouse Dock	North	45	0	6	0	26	0	6	2019	0	784
Wapping Basin	North	50	0	5	8	26	0	1	3151	0	454
	South	50	0	6	0	26	0				
	West	40	0	6	0	25	0				
Wapping Dock	West	50	0	6	0	26	0	5	499	0	815
	South	50	0	6	0	26	0				
King's Dock	South	42	0	5	0	26	1	7	3896	0	875
Queen's Half-Tide Dock	West North	70	0	6	9	31	0	3	3542	0	445
	South	50	0	6	9	31	0				
Trafford Dock and Lock	Outer	30	0	Above 0	3	...	...	0	4102	0	419
	Inner	30	0	1	3	...	...				
Queen's Dock	West	50	0	Below 6	0	26	0	10	1564	0	1214
	South	60	0	6	6	28	9				
Coburg Dock	West	70	0	6	0	30	6	8	26	0	1053
Canal Dock, East of Brunswick Dock (*less Railway Company's portion*) . .	West	25	0	1	0	27	0	0	4635	0	450
Brunswick Dock	North	60	0	6	6	27	0	12	3010	0	1086
	West	42	0	5	6	26	0				
Brunswick Half-Tide Dock	West	45	0	6	0	26	6	1	3388	0	491
Harrington Dock	South	60	0	12	0	31	0	9	256	0	1023
Do. Lock (131 ft. long) . .	West	22	0	5	9	31	0	0	320	...	...
Herculaneum Dock	North	80	0	12	0	31	0	7	2581	0	596
	South	60	0	12	0	31	0				
Do. Branch Dock	...	...		...	...	...	...	2	853	0	577
Total Water area and Quay space of the Liverpool Docks								349	4382	23	344

LIVERPOOL BASINS.

LIVERPOOL BASINS.	Width of Entrance. Ft.	In.	Height of Piers above Datum. Ft.	In.	Water Area. Acres.	Yds.	Lineal Quayage. Miles.	Yards.
Canada Basin	390	0	N30 S32	0 0	9	2805	0	846
Sandon Basin	200	0	31	0	6	904	0	702
George's Ferry Basin	67	0	23	8	0	1344	0	160
Chester Basin	36	0	22	2	0	2568	0	288
Anderton Basin	46	0	25	7	0	1422	0	175
Eagle Basin	50	0	25	10	0	3991	0	260
South Ferry Basin	60	0	30	6	0	2927	0	205
Total Water Area and Quay Space of the Liverpool Basins					18	1441	1	876
Do. do. do. Docks					349	4382	23	344
TOTAL					368	983	24	1220

AREA OF THE DOCK ESTATE.

Liverpool	1,077¾ Acres.
Birkenhead	506 ,,
Total	1,583¾ Acres.

LIVERPOOL GRAVING DOCKS.

NAME AND POSITION.	Width of Entrance. Ft.	In.	Sill below Datum. Ft.	In.	Coping at Hollow Quoins above Datum. Ft.	In.	Length of Floor. Ft.	In.	Total Length of Floor. Ft.	In.
Langton, No. 1 (South) Outer	60	0	6	0	27	0	448	0		
Langton, No. 1 (South) Inner	60	0	6	0	27	0	500	0		
No. 2 (North) Outer	60	0	6	0	27	0	500	0		
No. 2 (North) Inner	60	0	6	0	27	0	448	0	1896	0
Huskisson Lock as a Graving Dock	80	0	6	6	26	0	...		395	0
Sandon, No. 1 (East)	60	0	3	6	26	0	565	0		
,, No. 2	70	0	3	6	26	0	565	0		
,, No. 3	60	0	3	6	26	0	565	0		
,, No. 4	70	0	3	6	26	0	565	0		
,, No. 5	45	0	3	6	26	0	565	0		
,, No. 6 (West)	45	0	3	6	26	0	565	0	3390	0
Clarence, No. 1 (North) Outer	45	0	3	0	26	6	451	0		
Clarence, No. 1 (North) Inner	45	0	0	6	18	0	289	0		
,, No. 2 (South) Outer	45	0	3	0	26	6	454	0		
,, No. 2 (South) Inner	32	10	0	6	18	0	286	0	1480	0
Princes	45	0	5	9	28	2	...		277	4
Canning, No. 1 (North)	35	9	Sill above Datum. 1	8½	23	3	436	0		
,, No. 2 (South)	35	9	Sill below Datum. 0	0½	23	3½	482	0	918	0
Queen's, No. 1 (East)	42	0	1	8¼	27	7¾	465	0		
,, No. 2 (West)	70	0	3	6	27	5	467	0	932	0
Brunswick, No. 1 (East)	41	0	2	6	26	6	460	0		
,, No. 2 (West)	41	6	2	6	26	6	462	0	922	0
Herculaneum, No. 1 (West)	60	0	4	0	26	0	758	6		
,, No. 2 (Middle)	60	0	4	0	26	0	753	0		
,, No. 3 (East)	60	0	4	0	26	0	768	0	2279	6
Total Length of Floor of the Liverpool Graving Docks									12,489	10

BIRKENHEAD GRAVING DOCKS.

Name and Position.		Width of Entrance.		Sill below Datum.		Coping at Hollow Quoins above Datum.		Length of Floor.		Total Length of Floor.	
		Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
West Float	No. 1. East	60	0	4	9	25	0	930	0		
	No. 2. Middle	50	0	7	9	25	0	750	0		
	No. 3. West	85	0	7	9	25	0	750	0	2,430	0
Total Length of Floor of the Birkenhead Graving Docks										2,430	0
Ditto of the Liverpool Graving Docks										12,489	10
Total										14,919	10

LIVERPOOL GRIDIRONS.

Site.	Breadth of Gridiron.		Length.	
	Ft.	In.	Ft.	In.
Clarence Graving Dock Basin	25	6	313	6
The Blocks are laid 2 feet 2 inches below the Datum at the South end of the Gridiron, and 3 inches below at the North end				
King's Pier . . The Blocks are laid at the level of the Datum . . .	26	0	509	0
Total Length of the Liverpool Gridirons			822	6

LANDING STAGES.

LIVERPOOL.—Stage 2,063 feet long, by 80 feet wide, has 7 Bridges connecting it with the Shore, besides a Floating Bridge 550 feet in length, and 35 feet in width, by means of which an easy incline for Carriage Traffic is maintained at all times of the Tide. The Stage was destroyed by fire 28th July, 1874, and afterwards restored.

BIRKENHEAD.—Woodside Stage 800 feet long, 80 feet wide ; 2 Bridges from the Shore.

NOTE.—The South End of the Woodside Stage, for a length of 300 feet, including one of the Bridges, is appropriated to the use of the Birkenhead Corporation. The 500 feet Northwards, and the other Bridge, is under the superintendence of the Dock Board. In connection with this Stage there is a Floating Bridge, 678 feet in length by 30 feet in width, similar to that at the Liverpool Stage.

Wallasey Stage, 350 feet long, 70 feet wide, connected with the Shore by 2 Bridges and platforms on Iron Piers.

Docks not belonging to the Mersey Docks and Harbour Board.		Width of Entrance.				Level of Sill. Above Datum.		Level of Sill. Below Datum.		Level of Coping above Datum.		Water Area.	
			Ft.	In.		Ft.	In.	Ft.	In.	Ft.	In.	Acrs.	Yds.
The Bridgewater Navigation Company.													
Duke's Dock		Outer	40	0		—		4	6	25	6	2	1336
		Middle	28	10		0	6	—		22	9	—	
		Inner	40	0		—		6	0	25	0	—	
Canal Dock East of Brunswick Dock (Railway Co.'s)			25	0		—		1	0	31	0	0	2334
The London and North Western Railway Company.													
Garston Docks	N.	West	55	0		—		6	8	26	0	8	1294
		South	55	0		—		—		—		—	
	S.	West	50	0		—		4	8	26	0	6	1200
												17	1324

The Leeds and Liverpool Canal is in communication with Stanley Dock through four Locks and five intermediate Basins. The Locks are each 81 feet long by 16 feet 6 inches wide, and the total rise is 46 feet 6 inches. The Level of the Water in the Canal is 58 feet above the Datum.

BIRKENHEAD DOCKS.

BIRKENHEAD DOCKS.	Position and Width of Entrance or Passage.			Sill below Datum.		Coping at Hollow Quoins abv. Dtm.		Water Area.		Lineal Quayage.	
		Ft.	In.	Ft.	In.	Ft.	In.	Acrs.	Yds.	Miles.	Yds.
West Float . . . . . East		100	0	7	6	26	6	52	319	2	210
Basin near Canada Works . . West	North	50	0	...	...	...	...	1	2554	0	543
" " " . . . East	North	50	0	...	...	...	...	1	84	0	390
East Float		...	...	...	...	...	...	59	3786	1	1506
Corn Warehouse Dock		30	0	O.D.S.		26	0	1	453	0	555
Railway Companies' Basin		...	...	...	...	...	...	0	606	0	113
Wallasey Dock		...	...	...	...	...	...	12	3813	0	1261
Passage to do.		50	0	Below. 9	0	26	0	0	1333	0	234
Inner Northern Entrances	North	100	0	9	0	26	0	...	...	0	242
Lock 198 feet long	Middle	30	0	...	...	26	0	0	667	0	264
Inner Sill		...	...	9	0	..	...	...	...	...	...
Outer Sills		...	...	12	0	...	...	...	...	...	...
Lock 274 feet long	South	50	0	...	...	26	0	0	1522	0	300
Inner Sill		...	...	9	0	...	...	...	...	...	...
Outer Sills		...	...	12	0	...	...	...	...	...	...
Alfred Dock		...	...	...	...	...	...	8	2922	0	482
Outer Northern Entrances—											
Lock 348 feet long	North	100	0	12	0	31	0	0	3888	0	352
Lock 198 feet long	Middle	30	0	12	0	26	0	0	667	0	377
Lock 398 feet long	South	50	0	12	0	26	0	0	2222	0	391
Egerton Dock	West	70	0	7	4	25	0	3	4011	0	754
Morpeth Dock	West	70	0	5	5	25	0	11	2404	0	1299
Railway Company's Basin	South	25	0	O.D.S.		26	0	0	3144	0	319
Morpeth Branch Dock	West	85	0	...	...	26	0	4	243	0	637
Morpeth Lock 398 feet long . . .	East	85	0	Below. 12	0	26	0	0	3777	0	441
Total Water Area and Quay Space of the Birkenhead Docks. . .								159	4535	9	110

BIRKENHEAD BASIN.

BIRKENHEAD BASIN.	Width of Entrance.		Height of Piers above Datum.		Water Area.		Lineal Quayage.	
	Ft.	In.	Ft.	In.	Acrs.	Yds.	Miles.	Yds.
North Basin	500	0	31	0	4	2843	0	669
Total Water Area and Quay Space of the Birkenhead Basin					4	2843	0	669
Do. do. do. . . . Docks					159	4535	9	110
Total					164	2538	9	779

TOTAL AREA OF THE LIVERPOOL AND BIRKENHEAD DOCKS AND BASINS.

	Acrs.	Yds.	Acrs.	Yds.
Total Water Area and Quay Space of the Liverpool Docks and Basins	368	983	24	1220
Total Water Area and Quay Space of the Birkenhead Docks and Basin	164	2538	9	779
Total	532	3521	34	239

DISCUSSION.

Mr. B. Martell (Member of Council): My Lord, might I say that although this is a Paper that cannot be discussed, as I conceive, still I am sure that the members of the Institution would not like it to pass by without our expressing our gratefulness to Mr. Lyster for bringing together such an immense amount of facts with regard to Liverpool. I thought I knew something about Liverpool, but I find that before hearing this Paper read I knew nothing. This is, indeed, a most valuable Paper, which has given us a vast amount of detailed information, which, I think, has never been collected together in this form before. I am sure that I only express the opinion of the members of the Institution in stating the great interest we have all felt in listening to this Paper.

Mr. W. Laird (Member): My Lord and Gentlemen, the same thing occurred to my mind; and although, no doubt, this information has been recorded, it could not have been brought before us to-day unless a very careful record had been kept for many years with regard to what has been done at Liverpool; still, it has been brought together so ably by Mr. Lyster, that it will be most useful and most interesting, not only to us at this meeting, but I feel satisfied it will be looked upon as a most useful summing up of what is of the deepest interest to everybody connected with the trade and prosperity of this city. Comprehensive although the Paper is, I think on one or two points Mr. Lyster has hardly succeeded in conveying to this meeting all he has had to do with the works. He does not particularly mention that when the Corporation of Liverpool in 1856 or 1857 first made efforts for taking over the Birkenhead Dock Estate it was then in an incomplete condition, and although for the first few years Mr. Hartley was the head and consulting engineer, yet the bulk of the labour of completing the construction of the Birkenhead Dock Estate in accordance with the Acts of Parliament fell upon Mr. Lyster. There is also one other little thing which, although I followed the Paper pretty closely, I did not notice, and that is the application of the powerful pumping machinery to raising the level of the water in the basin or dock, out of which the graving docks have an entrance, in order that when the tide of the day would fall short of giving a sufficient depth of water on the blocks of those graving docks, by using this powerful machine at the top of high water, and some short time afterwards, the level of the water in the basin is raised so much as to give a depth of water on the blocks which makes it possible in this artificial and ingenious way to put vessels in those graving docks, although of a greater draught of water than the ordinary tide of the day would have admitted being so placed in the graving docks. This has on several occasions proved to be of the very greatest advantage, and I think it is the first application of the kind on a large scale. The basin to which I refer is the Sandon Dock, and has five or six graving docks opening out of it, and up to this time the pumping machinery, made by Messrs. J. & H. Gwynne, of Hammersmith Engine Works London, has done its work with complete satisfaction. I think that this is a very useful application of pumping power, which has extended and developed very much of late years. I believe I am correct in stating that the idea was that of Mr. Lyster, and it is only right I should mention that in this Paper, comprehensive though it is, we do not find any mention of that most useful addition to the dock system on the Liverpool side. With regard to the very great interest of the Paper, I am sure we must all agree with Mr. Martell in what he has said about it, and although many of the gentlemen here may be familiar with Liverpool and its history, I am sure Mr. Lyster, in having brought together

so many facts telling us of its gradual progress and development, and drawing our attention to the physical condition of the river and its tributaries, has done most useful work. I believe if those who have had to do with the Manchester Ship Canal in its earlier stages had thoroughly understood the physical condition of the river and the difficulties with regard to navigation they would have approached that subject with very much more hesitation than they did.

Sir Nathaniel Barnaby (Vice-President): My Lord and Gentlemen. I would say one word before we break up with regard to this Paper. The members of my own profession will forgive me if I say that the great object of attraction here to me is the visit to the docks, and the hearing of Mr. Lyster's Paper. Those of us who have been concerned in building large ships, and particularly those of us who have not had the opportunity of making that inspection of the docks now afforded to us by our friends at Liverpool must have felt very great pleasure in coming down here to share in the enjoyment we have had this morning in listening to this most interesting Paper on the docks. I think the dock engineers and shipbuilders should work together, and that it is right we should know what the engineers are doing, also that Mr. Lyster should know what our views are as to what form ships should take in the future; what will be their probable requirements, and the extent of dock accommodation which is necessary. We are very anxious to know what the facilities are which are afforded by nature, and also those afforded by the aid of art to this great port, and I would express our thanks to Mr. Lyster for the way he has dealt with the subject, and for the vast amount of information which he has conveyed to us through his Paper.

Mr. G. F. Lyster (Associate): My Lord, I would say a word or two with reference to Mr. Laird's remarks about the pumping machinery at Sandon Dock. It is no doubt a most important addition to our dock estate, and contributes largely to its working capacity. I by no means intend that your lordship, or the members of the Institution present should pass it by, as I am in hopes you will visit it this afternoon. It was, however, a subject of so much detail that if I had entered upon it fully it would have lengthened my Paper very unduly, besides which, there are other works of an equally important character affecting the convenience of the port which I also ought to have mentioned had I alluded prominently to the pumping machinery, and these should also, if time permits, be visited by your Institution. I am bound to add, however, that the magnificent centrifugal pumps carried out by Messrs. Gwynne, of the Hammersmith Works, London, are well worthy of careful inspection, and will, I think, please everybody that sees them, as they not only do their work most efficiently, but are at the same time a specimen of engine work of the very highest type.

The President: Gentlemen, I do not see anybody rising, and I am obliged to look again at the clock, although you may think I am very troublesome, and that I am always looking at the clock. However, I am sure I may convey to Mr. Lyster our united and unanimous thanks for the able and interesting and valuable Paper with which he has furnished the meeting to-day.

NOTES UPON LOSSES AT SEA.

By Francis Elgar, Esq., LL.D., F.R.S.E., Member of Council.

[Read at the Twenty-seventh Session of the Institution of Naval Architects, at Liverpool, 28th July, 1886; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

An attempt is made in the present Paper to analyse the loss of life caused by the wrecks, or total losses, of British merchant ships at sea, during the three calendar years, 1881 to 1883; and to consider in detail, as far as the necessary limits of space will permit, some of the principal causes of loss, and the extent to which they operated in producing loss of ships, and of lives, at sea. A general analysis has been made of all losses for the three years named; and it has been continued for the two succeeding years, 1884 and 1885, so far as steamers and iron sailing ships, of and above 300 tons gross register, are concerned. The subject is one in which many members of this Institution—among whom are some of the designers and builders of ships that have been lost—are deeply interested. It has, therefore, occurred to me that this might be a fitting occasion upon which to lay before the Institution a few considerations that have been suggested by a study, from the naval architect's point of view, of the known facts respecting ships that have recently foundered.

I hardly need remind the meeting that the three years 1881 to 1883 form the triennial period that has caused so much controversy as to whether loss of life at sea is increasing or not; and it includes the worst year that has yet been been known for loss of life among seamen, viz., the year 1881. This has become known as Mr. Chamberlain's year, because it was upon the returns of mortality among seamen for that year, his statement was based that the loss of life among the seamen employed had reached the annual rate of 1 in 60. It seems to have been quite by accident that this particular year was taken by Mr. Chamberlain; for he said, in moving the second reading of his "Bill to provide for the greater security of Life and Property at Sea," in the House of Commons, on the 19th May, 1884, that it was simply because, at the time when he first came to deal with the question, 1881 was the last year for which we had any returns.

The important questions that have been raised respecting the safety of life and property at sea, and the effect upon losses of various circumstances, such as the laws concerning Marine Insurance and the liability of shipowners, the action of the Marine Department of the Board of Trade and of the Wreck Inquiry Courts, and the condition and efficiency of merchant officers and seamen, are being closely inquired into by the Royal Commission on Loss of Life at Sea. I do not propose to touch upon the general aspects of any of those questions, nor to enter upon any argument as to the variation in the rate of mortality at sea during recent years, and the causes of such variation. My object is the more special one of describing, and, to some extent, remarking upon, the technical particulars of con-

struction, condition, and loading that are procurable respecting ships in which members of this Institution are most interested, viz., steamers and sailing vessels that have foundered while employed in over-sea carrying trades.

In order to show what proportion the losses of ships, and of lives, by foundering at sea, bears to the total number of losses recorded in the official returns, it is necessary to take as a starting point the total number of losses from various causes, in all classes of vessels, that occurred during the period under consideration. We will, therefore, commence by taking the whole number of total losses of ships, and of the lives lost in them, during the three calendar years 1881 to 1883.

The whole number and tonnage of British Ships (*i.e.*, belonging to the United Kingdom and the Colonies), which were wrecked, or totally lost, in each of the three years 1881 to 1883, and the number of lives lost in them, are shewn in Table I.

TABLE I.*

REGISTERED AND UNREGISTERED VESSELS BELONGING TO THE UNITED KINGDOM AND THE COLONIES, WHICH WERE LOST AT SEA, AND IN HARBOURS AND RIVERS.

Year.	Vessels totally lost.	Tonnage of vessels totally lost.	Vessels totally lost in which loss of life occurred.	Lives lost.		
				Crew.	Passengers.	Total.
1881	1,387	385,166	444	3,278	558	3,836
1882	1,149	341,387	278	2,078	90	2,168
1883	1,206	340,712	351	2,692	195	2,887
Total for the 3 years.	3,742	1,067,265	1,073	8,048	843	8,891

The following additional lives were lost, during the same period, by casualties to British and Colonial ships at sea, and in harbours and rivers, which did not result in total loss of the ships themselves.

TABLE II.*

Year.	Casualties to ships in which loss of life occurred.	Lives lost.		
		Crew.	Passengers.	Total.
1881	169	253	38	291
1882	128	227	61	288
1883	219	294	20	314
Total for the 3 years.	516	774	119	893

* Casualties (Wreck Statistics, 1875-83), Parliamentary Return [C—4335] 1885, page 37.

The total number of lives lost at sea, and in harbours and rivers, by wrecks of, and casualties to, British and Colonial ships, during the year 1881, was, therefore, 3,531 seamen and 596 passengers; in 1882, 2,305 seamen and 151 passengers; and, in 1883, 2,986 seamen and 215 passengers.

The figures for loss of life that are here being dealt with, are confined to losses by wreck and casualty. There were also losses of life by drowning, or by accident other than drowning, where there was no wreck of, or casualty to, the ships in which they occurred. These will not be included in any of the present tables; but some general particulars relating to them will be found on page 58.

The term "ship," as used in these tables, applies to every description of vessel that is used in navigation, and is not propelled by oars. It includes fishing vessels, yachts, barges, and all other small craft. "Wreck," means the absolute destruction of a ship, or some form of casualty which results in her removal from the register of British ships; and "casualty," means any occurrence which, though more or less serious to the ship herself, does not result in the total loss of the ship, or in her removal from the register. Ships that are described as lost at sea, include those that are lost upon any coasts all over the world; all, in fact, except those lost in rivers and harbours.

Tables I. and II. give not only the losses of ships and of lives that took place at sea—*i.e.*, at sea and upon all coasts—but also those that happened in rivers and harbours. The first step to be taken, therefore, in attempting an analysis of the losses of, and from, trading merchant ships at sea, is to eliminate from the tables, the figures that relate to losses in rivers and harbours. This is done in Tables III. and IV.

TABLE III.*

Registered and Unregistered Vessels Belonging to the United Kingdom and the Colonies, which were lost at Sea.

Year.	Vessels totally lost.	Tonnage of vessels totally lost.	Vessels totally lost in which loss of life occurred.	Lives lost.		
				Crew.	Passengers.	Total.
1881	1338	377,971	434	3226	354	3580
1882	1105	334,031	269	2063	82	2145
1883	1148	327,408	346	2671	194	2865
Total for the 3 years.	3591	1,039,410	1049	7960	630	8590

* Casualties (Wreck Statistics, 1875–83) Parliamentary Return [C.—4335] 1885, page 37.

The following additional lives were lost during the same period by casualties to British and Colonial ships at sea.

TABLE IV.*

Year.	Casualties to ships in which loss of life occurred.	Lives lost.		
		Crew.	Passengers.	Total.
1881	157	242	35	277
1882	106	189	32	201
1883	190	261	15	276
Total for the 3 years.	453	692	82	754

The total number of lives lost at sea, by wrecks of, and casualties to, British and Colonial ships during the year 1881, was, therefore, 3,468 seamen and 389 passengers; in 1882, 2,252 seamen and 114 passengers; and, in 1883, 2,932 seamen and 209 passengers. And by comparing Tables I. and II. with Tables III. and IV., it will be seen that 49 vessels, and the lives of 63 seamen and 207 passengers were lost by wreck and casualty in rivers and harbours in 1881; 44 vessels, and the lives of 53 seamen and 37 passengers were lost in rivers and harbours in 1882; and 58 vessels, and the lives of 54 seamen and 6 passengers were lost in rivers and harbours in 1883. The lives of passengers lost in rivers and harbours during the years 1881 and 1882, thus equalled about one-half the whole number of lives of passengers that were lost at sea.

The figures given above relate to vessels belonging to the Colonies, as well as to those belonging to the United Kingdom. The vessels with which we are specially concerned, however, are those belonging to the United Kingdom; and we will, therefore, strike out of the Tables all figures that relate to Colonial ships. This is, indeed, necessary in making any detailed analysis of losses, because the returns of losses of Colonial ships are not sufficiently complete to enable any exact computation to be made in which they are included. In the next table, therefore, British ships belonging to the United Kingdom, and that have been totally lost at sea, will alone appear:—

* Casualties (Wreck Statistics, 1875-83). Parliamentary Return (C.—4335) 1885, page 31.

TABLE V.*

REGISTERED AND UNREGISTERED VESSELS BELONGING TO THE UNITED KINGDOM WHICH WERE LOST AT SEA.

Year.	Vessels totally lost.	Tonnage of vessels totally lost.	Vessels totally lost in which loss of life occurred.	Lives lost.		
				Crew.	Passengers.	Total.
1881	973	297,341	358	2,737	213	2,950
1882	732	260,875	209	1,720	30	1,750
1883	776	260,728	288	2,366	90	2,456
Total for the 3 years	2,481	818,944	855	6,823	333	7,156

The following additional lives were lost during the same period by casualties to vessels at sea belonging to the United Kingdom :—

TABLE VI.*

Year.	Casualties to ships in which loss of life occurred.	Lives lost.		
		Crew.	Passengers.	Total.
1881	123	196	19	215
1882	89	151	26	177
1883	156	206	4	210
Total for the 3 years	368	553	49	602

The total number of lives lost at sea by wrecks of, and casualties to, vessels belonging to the United Kingdom during the year 1881 was, therefore, 2,933 seamen and 232 passengers; in 1882, 1,871 seamen and 56 passengers; and, in 1883, 2,572 seamen and 94 passengers.

For our present purpose, we also require to omit from our Tables the figures relating to another class of ships, viz., unregistered ships that belong to the United Kingdom. "When we come to make computations, which will be in any sense trustworthy as showing "the proportion which the number of ships lost bears to the number of ships on the "register, and the proportion of lives lost to the number of persons employed, we have to "throw out of our calculations (1) ships belonging to the Colonies, (2) unregistered ships "belonging to the United Kingdom; and we have to do this because, first, we only have a "very rough estimate of the number of hands employed in Colonial ships; secondly, we "have no record, and no trustworthy estimate of hands employed in small craft belonging "to the United Kingdom, which are not registered as British ships; thirdly, we have no

* Casualties (Wreck Statistics, 1875–83). Parliamentary Return (C.—4335) 1885, page 29.

" means of ascertaining, with any degree of accuracy, the tonnage of any unregistered ships " and vessels; and, fourthly, as regards unregistered fishing vessels and boats, we only " have estimates of their number, and those estimates are not trustworthy, and are, for " purposes of close deduction, useless."*

" Registered in the United Kingdom " means that the vessel's port of registry is situated within the limits of the United Kingdom; and, for this purpose, the United Kingdom does not include the Channel Islands or the Isle of Man.

The unregistered vessels lost at sea, that thus require to be thrown out of Table V., for the year 1881,are 96 in number, with an aggregate tonnage of 1,400 tons; for the year 1882, 57 in number, with an aggregate tonnage of 755 tons; and, for the year 1883, 55 in number, with an aggregate tonnage of 548 tons. These are all, of course, very insignificant craft. They consist chiefly of small traders under 15 tons measurement, and fishing vessels that are lettered and numbered under the Sea Fisheries Act. The lives of seamen lost from these wrecks were 264 in 1881, 52 in 1882, and 49 in 1883. No passenger was lost from them.

The whole number of fishing craft employed at sea are not included among the last-named class of vessels, many being registered under the Merchant Shipping Act of 1854. The following losses occurred at sea during the three years under consideration among registered fishing vessels :—In 1881, 97 vessels and 233 lives; in 1882, 72 vessels and 196 lives; and in 1883, 122 vessels and 430 lives.

If we now proceed to cast out of our tables the figures relating to losses at sea of fishing vessels, registered and unregistered, and of all other small unregistered craft, we shall then arrive at the losses at sea, from all causes, of British ships that are registered in the United Kingdom, exclusive of vessels employed in fishing. The result is shown in Table VII.

TABLE VII.†

REGISTERED VESSELS BELONGING TO THE UNITED KINGDOM (NOT INCLUDING FISHING VESSELS) WHICH WERE LOST AT SEA.

Year.	Vessels totally lost.	Tonnage of vessels totally lost.	Lives lost.		
			Crew.	Passengers.	Total.
1881	780	290,255	2,240	213	2,453
1882	603	256,990	1,472	30	1,502
1883	599	252,812	1,887	89	1,976
Total for the 3 years	1,982	800,057	5,599	332	5,931

* Mr. T. Gray, C.B. Minutes of Evidence taken before the Royal Commission on Loss of Life at Sea. 1885. Page 4, Q. 22.
† Casualties (Wreck Statistics, 1875–83). Parliamentary Return (C.—4335) 1885, page 42.

The following additional lives were lost during the same period by casualties to the same classes of vessels at sea, which casualties did not result in the total loss of the ships:—In 1881, 112 seamen and 18 passengers; in 1882, 96 seamen and 24 passengers; and, in 1883, 105 seamen and 1 passenger. The whole number of lives of masters and seamen lost by wrecks and casualties at sea to British ships registered in the United Kingdom was, therefore, 2,352 in 1881, 1,568 in 1882, and 1,992 in 1883. The whole number of lives of passengers lost under the same circumstances was 231 in 1881, 54 in 1882, and 90 in 1883.

It has already been pointed out that the figures relating to loss of life at sea, which are included in these tables, are limited to losses of life that are caused by wrecks of, or casualties to, ships. It may be well to call attention here to the losses of life by drowning, or by accident other than drowning, where there is no wreck of, or casualty to, the ships from which they occur. This information has been furnished by Mr. Thomas Gray, in his evidence before the Royal Commission on Loss of Life at Sea, for the calendar year 1881; but it cannot be accurately given for any other year, because the returns from which it is compiled contain duplicate entries, a number of deaths in fishing vessels, and other sources of error. The figures for the single year 1881 may, however, suffice as an indication of the proportion which the loss of life caused by the wrecks of ships bears to the total loss of life caused by accidents of all kinds at sea.

Table VIII. contains particulars of the whole number of violent deaths in ships registered in the United Kingdom, exclusive of deaths in fishing vessels.

TABLE VIII.

CORRECTED FIGURES FOR ONE YEAR.*

Year.	Masters and Seamen employed.	Lives of Masters and Seamen lost.				Proportion per annum.				Lives lost in Merchant Ships registered in the United Kingdom.		
		By total losses of ship.	By casualties of all kinds to ships, whether resulting in total loss or not.	By drowning from all causes.	By drowning and other accidents.	Lives lost by total losses of ships to persons employed.	Lives lost by casualties of all kinds to ships to persons employed.	Lives lost by drowning to persons employed.	Lives lost by drowning and other accidents to persons employed.	Crew.	Passengers.	Total.
1881	186,719	2,240	2,352	3,084	3,278	1 in 83·36	1 in 79·39	1 in 60·54	1 in 56·96	3,278	231	3,509

We thus see that, besides the 2,240 lives of masters and seamen lost in 1881 from ships that were totally wrecked, and 2,352 lost through casualties of all kinds to ships, 732 were

* Minutes of Evidence taken before the Royal Commission on Loss of Life at Sea. 1885. Q. 132.

lost by drowning from causes not connected with casualties to ships, and 194 more were lost through accidents other than drowning. The drownings not connected with casualties to ships include cases of falling overboard or being washed overboard from ships, falling from wharfs and quays, accidents in boats, carelessness or recklessness, intoxication, drowned while bathing, found drowned, supposed drowned, &c. The accidents other than drowning include cases of falling from aloft, falling into holds, killing by spars or gear falling from aloft, poisoning, murder, sunstroke, death from exposure, scalding, injuries from machinery, &c.

The statistics of this subject are very voluminous and complicated, and it is often extremely difficult, in endeavouring to extract precise information from the numerous returns and documents relating to it, to understand what ships or what deaths are being dealt with. Want of uniformity in the basis upon which the official returns are prepared renders many of them valueless for any real practical purpose. To this cause may, I believe, be attributed, in a very large degree, the misunderstandings that have arisen between shipowners and the Board of Trade respecting the extent and the causes of losses at sea.

A general view of how matters stand in connection with the loss of life at sea during 1881, 1882 and 1883 may be obtained by reference to Table VIII. p. 59 and to the Table in Appendix A. p. 78. The former table gives 3,509 as the total number of lives of masters, seamen, and passengers lost from ships registered in the United Kingdom in 1881, 3,278 as the total number of lives of masters and seamen lost by drowning and all other accidents, 3,084 as the total number of lives of masters and seamen lost by drowning from all causes, 2,352 as the total number of lives of masters and seamen lost by drowning through casualties of all kinds to ships, and 2,240 as the total number of lives of masters and seamen lost from ships that were wrecked or totally lost.

Referring now to the Table in Appendix A., which contains figures relating to British ships that were totally lost during the three years 1881 to 1883, we see it is the lowest figure, 2,240, that is therein dealt with for the year 1881; and the corresponding figures for the other years. We find this figure opposite Item 7 of the Table, Appendix A., under the year to which it relates, 1881. That item gives the number of ships totally lost, and the number of lives lost from them, that are contained in Table VII. p. 58. The figures in Items 7 to 12 of the Table in Appendix A. are taken from Tables I. to VII. pp. 54–58 in the manner explained in the column of remarks of the first-named Table; and it is probably unnecessary to say more about them.

Coming now to Item 7 of the Table, Appendix A, which relates to the whole number of British ships, registered in the United Kingdom, excluding fishing vessels, that were lost from all causes at sea during each of the three years 1881 to 1883, we proceed to consider the character of the losses included therein. The first step will be to divide them

into founderings, missing ships, collisions, strandings, and losses from other causes. That is done in Items 3 to 6 of the Table; the sum total of the figures at those items giving the figures at Item 7.

The chief features of this part of the Table are that nearly three-fourths of the whole number of lives of masters and seamen lost were lost in foundered and missing ships, or 4,036 out of 5,599; 22·2 per cent. were lost from stranded ships, 4·6 per cent. from collisions, and only 60 lives in all from other causes. The "other causes" include fire, spontaneous combustion of coal, explosions, collisions with ice or floating wreck, want of pilots, defective tow ropes, intentional destruction, &c., &c. There may, of course, be losses under the head of missing ships that are due to some of those causes. Losses are only credited to "other causes" when there is direct evidence obtainable respecting them, The item "missing ships" would include all cases of spontaneous combustion that may have resulted in total loss of ships and crews, and all cases of collision between two ships, or between a ship and ice, or a ship and floating wreck, where the ships concerned have been lost with all hands. It can hardly be considered a far-fetched supposition that an appreciable proportion of the losses of missing ships happen from these causes. Cases of collision will occur to everyone where perhaps no lives would have been saved had there been an unfavourable combination of circumstances existing at the time. Take the well-known case of the Royal Mail Steamer "Douro" and the Spanish Steamer "Yrurac Bat," where both vessels went down within twenty minutes after the collision, and where such of the passengers and crew as did not go down with them were rescued from the boats by a passing steamer. Or, take the still better known, and more recent, case of the collision between the Oregon and an unknown schooner. It is not unreasonable to suppose that such an accident might have happened in circumstances of weather and of distance from land and all friendly help, that would have prevented any lives being saved. Had that been the case few would probably have believed that the loss was caused by collision. Then as regards collision with floating dangers such as ice and wrecks, we find the Wreck Commissioner attributing the losses of the steamers Fernwood, Preston, Clandon and other vessels, in the North Atlantic, during the early part of 1885, to contact with fields of ice, or icebergs, that were known to be floating about there at the time.

It has not appeared desirable to increase the size of this table by including passengers in it, and it may suffice to say here upon that head that out of the 332 passengers (see Table VII. p. 58) lost during the three years from ships that were wrecked, 129 were in foundered and missing ships, 184 in stranded ships, 17 in ships in collision, and 2 in ships lost by other causes. Out of the 184 passengers in stranded ships, 162 were lost during the single year 1881.

The class of losses which is the most appropriate for our consideration is that of the foundered and missing ships. Strandings and collisions are almost entirely due to

causes which lie outside the sphere of influence of those who design or build the ships that are concerned in them, although there may be cases in which they occur through defects in or breakdown of fittings, machinery, or tackle. There are a few instances also in which vessels have been run ashore in order to prevent their foundering in deep water, and where the loss, which was virtually by foundering has thus become technically a loss by stranding. This was the case with the S.S. Ludworth, where a leak was sprung at sea, and the captain, fearing the vessel would sink in deep water turned her head in towards the shore and succeeded in beaching her just before the fires were extinguished. It would be impossible for me, however, to find time to go over all the returns, and to judge of and eliminate every questionable case of this kind, while if that were done the broad facts and the deductions that may be drawn from them, would probably remain as now stated, I have therefore contented myself with taking the losses properly assignable to foundering to be as shown in the official tables.

We will proceed, therefore, to consider the cases of the 608 ships that foundered or were missing, and of 4,036 lives lost in them, during the three years 1881 to 1883; and as it appears that 344 of those ships were small craft under 300 tons gross register, chiefly employed in coasting trades (see Item 2, Appendix A), we will leave them out of account and confine our attention to the more manageable remainder of 264 ships in which 3,006 lives were lost.

The 264 ships thus selected embrace all the vessels in which members of this Institution are likely to have a special interest. They include all British vessels of any size or importance that have foundered at sea—all that are not below 300 tons gross register—and also the vessels from which the greatest proportion of lives were lost. Out of the total number of British and Colonial ships of all sizes, amounting to 3,742, that were totally lost, and 8,048 lives in them, during the years 1881, 1882, and 1883, we thus find ourselves left with 264 foundered and missing ships registered in the United Kingdom, of and above 300 tons gross register, in which 3,006 lives were lost.

It would be useless to speculate upon the causes of loss of those 264 vessels by merely considering them in the aggregate; and no opinion that might be formed in such a manner as to the degree to which the losses may have been preventible could have any practical value, or could be expected to convince anybody. We require to closely examine all the known circumstances attending the individual losses, and to consider in minute detail the classes of ships, the cargoes carried, and all matters affecting the seaworthiness of the vessels, before we can form any useful opinion respecting the general causes of loss. This has long been a very difficult matter for any one outside the Board of Trade to attempt; but an unpublished return made by the Board of Trade to the Load Line Committee about two years ago, which I have permission to use, enables it to be done, to a considerable extent, for the 264 vessels now under consideration. In the following remarks, and in the tables that will be referred to, I shall use the figures contained in that return.

In Item 1 of the Table, Appendix A, these 264 vessels are grouped according to the cargoes they carried, whether grain, coal, metal, timber, general, or other cargo, or in ballast. We thus see that grain and coal cargoes account for one-half of the whole number of ships, and more than one half of the whole number of lives lost; coal being responsible for one-third and grain for one-sixth. This, however, does not carry us far enough. We require to know, further, what number of those ships were steamers, and what number were sailing vessels; how many of the latter were of iron and how many of wood; and what were the various kinds of grain that were being carried by the ships when lost. We also require to know what proportion the quantity of each kind of cargo carried bears to the whole volume of the oversea carrying trade of the United Kingdom before we can judge whether the number of ships lost, in a particular trade, exceeds the general average of losses in all trades, or not. The data respecting the tonnage of cargoes carried oversea in British ships is, however, too imperfect to enable the latter requirement to be fulfilled. It is very much a matter of speculation whether the large number of losses in any particular trade—say, for instance, the coal trade—is due to the great bulk of that trade, or whether it may fairly be attributed to dangers special to the cargo, or to the ships in which it is carried. If there be reason to suppose it due to special dangers attending the cargo, or the ships that carry it, it is at any rate impossible to estimate the precise extent of those dangers by comparing the average of losses among British vessels carrying coal cargoes with the average of losses among all British cargo-carrying vessels that are actively employed.

We must, therefore, content ourselves, for the present, with a further analysis of the figures into which the 264 losses of ships, included in Item 1, Appendix A, have been divided; and we must unfortunately do without an exact comparison between the proportions of losses in ships of various types, or carrying different cargoes, and the proportion which those losses bear to the whole bulk of the over-sea carrying trade of the United Kingdom. The analysis referred to will be found in Appendix B, Tables I. to IV. pp. 54–56. Tables I. to III. are for the three years 1881 to 1883 respectively, and Table IV. contains the totals of the various items for those three years. A few remarks respecting the latter table will perhaps serve for all.

It will be seen by Table IV. that the 264 ships under consideration consist of 81 steamers, all of which are iron, 47 iron sailing ships, 127 wooden sailing ships, and 9 composite sailing ships. Out of the 3,006 lives lost in those ships, 1,295 were lost in steamers, 831 in iron sailing ships, 779 in wooden sailing ships, and 101 in composite sailing ships. Taking the 44 vessels that were lost with grain cargoes, we notice that 23 were steamers and 21 sailing ships: 9 out of the 23 steamers were laden with wheat, and 8 with barley; 15 out of the 21 sailing ships were laden with wheat, and 3 with rice; leaving only 3 sailing ships lost with grain cargoes other than wheat and rice. Thirty-three steamers and 53 sailing ships were laden with coal; 34 of the latter being

wooden vessels. Only 6 steamers were lost laden with cargoes other than grain, coal, metal, and general. Thirty-eight timber-laden vessels were lost, the whole of which were wooden sailing ships, except one that was composite. Their average age was 23 years, and 27 were not classed in any Register Society. Thirteen ships were lost while making voyages in ballast: they were all sailing vessels, 4 being constructed of iron, and 9 of wood. The 4 iron ships will be commented upon further on; but, as regards the 9 wooden ones it may now be pointed out that their average age was 24 years, and 5 were not classed in any Register Society.

We will now make another step in the analysis, and examine in detail the particulars, so far as they are known, of the losses tabulated in Appendix B. This will be done by passing from Table IV., Appendix B, to the Tables contained in Appendix D pp. 82–103. In the latter tables we have the particulars of the individual losses that are included in the figures given in Appendix B. First, we will deal with steamers only. Referring to Appendix B, Table IV., we find that 9 steamers laden with wheat were lost during the years 1881, 1882 and 1883. The particulars relating to those 9 steamers will be found in Appendix D, Table I. (*a*). Those tables have been brought down to the close of the year 1885 for steamers and iron sailing ships, because of the interest which attaches to recent particulars of the losses of those classes of vessels; but I do not intend to refer to the portions of the tables that relate to the years 1884 and 1885 in the present remarks. I did not receive the figures for the years 1884 and 1885 in time to comment upon them now, but I thought that, independently of anything that might be said about them, it would be useful to bring the tables down to date: and I have been able to do that owing to the valuable assistance of Mr. Thomas Gray, of the Board of Trade, who has kindly allowed the requisite information to be prepared in his department. In the present remarks, however, it will be understood that I am dealing only with the three years 1881, 1882 and 1883.

An abstract of the losses of steamers and iron sailing ships during the two years 1884 and 1885, and also an abstract of the losses of the same classes of vessels for the five years 1881 to 1885, is given in Tables I. and II., Appendix C.; those Tables being of the same form as the Tables in Appendix B.

Out of the nine wheat-laden steamers lost during the three years 1881 to 1883, four foundered and left survivors to tell the story of their loss; but five went down at sea with all hands, and the cause of loss can only, in those cases, be matter of inference. It will be observed, however, that four out of the five vessels that are missing are similar in type to three that foundered, viz., the narrow three-decked type such as were built in large numbers several years ago; and there is *prima facie* reason for supposing that the type of ship and the character of the loading being practically common to these vessels

the causes of loss would be similar. The five missing vessels are of the following registered dimensions :—

TABLE IX.

	Length. feet.	Breadth. feet.	Depth. feet.
No. 1. ...	270·0	33·5	24·0
No. 2. ...	286·0	37·0	22·8
No. 3. ...	285·0	35·2	24·5
No. 4. ...	270·2	34·2	24·6
No. 5. ...	285·5	35·0	24·4

These are all "three-deck" vessels, with water-ballast tanks and the ordinary deck erections.

Anyone who has investigated the stability of this class of vessels knows that, given a vessel of any of the dimensions in Table IX., except No. 2, she will have very little stability when laden with a homogeneous cargo that nearly or quite fills her. This is fully explained in a paper by Mr. B. Martell upon the "Causes of Unseaworthiness in Merchant Steamers," which is contained in Vol. XXI. of the Transactions of this Institution; and Mr. Martell has there given curves of stability for vessels of the narrow "three deck" type—notably for one 33·3 in breadth and 23 feet in depth, and for one 35·3 in breadth and 23 feet in depth—which show what amount of stability such vessels have when loaded in the manner described. What is often lost sight of, however, is that, in the case of these vessels, stability is not altogether regulated by freeboard, but often depends more upon the density of the cargo carried than upon the height of side which the vessel may have when laden. It is sufficiently obvious that when carrying a homogeneous cargo of comparatively small density, such as barley, a vessel may have less stability, even with a greater height of freeboard, than when carrying a heavier grain which does not completely fill her, when down to her load line, but which involves empty spaces being left in the 'tween decks. But it is, perhaps, not always understood that, when a homogeneous cargo is light enough to fill a vessel without immersing her to her load line, the extra freeboard thus obtained may not cause any increase of stability.

It appears to be sometimes assumed that, when a vessel is filled with a light homogeneous cargo which does not bring her to her load line, she will not only have greater freeboard, but will also have greater stability than when filled with a heavier cargo that does immerse her to that line; and it is perhaps under the influence of that assumption, it has been suggested that freeboard tables should be framed that would take stability into

account, and that would not admit of ships being immersed deeper in the water than the draughts at which they would be stable. The curves of stability in Fig. 1, Plate X. which I have taken from a report made by Mr. Martell to the Load Line Committee, show that the effect of additional freeboard upon the stability of a vessel filled with homogeneous cargo, may be practically *nil*, when it is obtained by means of a lighter cargo. The curves A and B are for cargoes that occupy 61·2 cubic feet, and 65·5 cubic feet, respectively, per ton of weight. In the first case the freeboard is 4 ft. 7 ins., and in the second case 5 ft. 1 in. The curves of stability are practically the same for each; and the curve B, which is for the greater freeboard, is rather less favourable than the other, because, up to 30° of inclination, it indicates less power of resistance to the heeling that would be caused by a shift of cargo. The comparative lightness of the cargo required to fill this vessel at the draughts named is due to the absence of water-ballast tanks in the holds. For that reason, and also because the deck erections are unusually small and light, the curves of stability are more satisfactory than they often are for vessels of her proportions.

The question of taking stability into account in the preparation of general tables of freeboard, was fully considered by the late Load Line Committee, with the result I have already described in a paper upon the load lines of ships, read before the Society of Arts in December last.* It was seen that stability is so intimately associated with stowage, that it is only possible to deal with it, by defining how vessels of various proportions and types are to be stowed; and that no mere provision of freeboard can make a ship safe, unless her stability is secured by proper stowage. The Load Line Committee did not feel called upon to deal with an independent problem of such magnitude and complexity as that: and the freeboard tables prepared by them, require to be used with the knowledge that vessels having the freeboards therein given, will be sufficiently stable, or not, according to the manner in which the cargo is stowed. Hence the importance of investigating, in all cases, before a vessel goes to sea, what amount of stability she will possess when laden with her intended cargoes.

But we do not require to confine ourselves to theoretical considerations in judging of the stability of the vessels referred to in Table IX. p. 65, when laden with the cargoes they carried. If we examine the cases of the four wheat-laden steamers that foundered, and of whose loss we know something, we find they point unmistakably towards instability. The dimensions of the first vessel were 260·9 feet × 32·4 feet × 22·8 feet. Her cargo shifted. She was thrown upon her broadside, could not be righted, and had to be abandoned. The second vessel was not one of the "three-deck" type. Her dimensions were 250·1 feet × 30·1 feet × 19·5 feet; but the shifting boards were insufficient and were not properly secured. She was thrown upon her broadside in a heavy sea, could not be righted, and was abandoned. The third vessel, 291·0 feet × 34·7 × 24·5, shipped water on deck which

* Journal of the Society of Arts, 11th December, 1885.

passed below, she careened over, could not be righted, and went down. The fourth vessel, 271·0 feet × 35·8 feet × 23·5 feet, accumulated water to leeward during a heavy gale. The vessel took a list which went on increasing, and the water below continued to increase. When she was abandoned the lee rigging was under water.

These facts connected with the losses of vessels that are similar in proportions, construction, and loading to the missing vessels respecting whose losses we have no information, strongly confirm the theoretical deductions that have been drawn from calculated particulars of the stability of this class of vessels. The general characteristics of those vessels in respect of stability is known by calculation to be small metacentric height, and small righting moments at all inclinations up to the angle at which they vanish altogether. The deficiency of stability is due to the circumstance that when full, or nearly full, of a homogeneous cargo such as wheat, the metacentre is low down in the vessel, owing to the narrow beam, and the centre of gravity of the cargo is high. It is to the combination of these two conditions—low position of metacentre and high position of centre of gravity—that the tendency to instability is due. The height of centre of gravity of cargo is often increased, and consequently the metacentric height reduced, in these vessels by water-ballast tanks, which extend in some instances throughout both holds, and are considerably higher than ordinary floors.

The stability of wheat-laden vessels of the type that includes the losses now under consideration would not be large if the cargo could be rigidly fixed in position in the ship, and if water could always be kept out of the holds, or the pumping power could be relied upon for keeping water under. But vessels laden with wheat, or with certain other grain cargoes, are likely to have exceptional demands made upon their stability by reason of the nature of the cargo. The holds and 'tween decks cannot be completely filled with grain, and even if that could be done in the first instance grain soon settles down after a vessel gets to sea, and leaves empty spaces at the top. Special precautions are now adopted by the Board of Trade, and had before been enforced by underwriters in America and Port Authorities in Canada, for making the stowage as perfect as possible. The present regulations respecting shifting boards of the full depth of a vessel, properly constructed feeders, and a certain proportion of grain to be carried in bags, all tend to prevent shifting. But those regulations are not always carried out in the most effective manner; and when they are, there is still a certain amount of shifting possible when a vessel is labouring at sea. The least possible shifting may be an important matter in a vessel whose stability is originally small.

By examining the individual cases before us, it will be seen that the shipment of water usually plays an important part in the first shifting of a grain cargo, and in the subsequent heeling and foundering of the vessel. Seas break on deck, the deck becomes filled with water, the weight of water gives the vessel a list, water finds its way below, it gets over into the lee bilge in continually increasing quantities, the grain settles over more and more, the pump suctions in the bilges are deficient in number or get choked

with grain, and the list increases so much that the vessel becomes unmanageable and has to be abandoned. That appears to be the brief history of many losses. The shifting boards that restrict the shifting of grain towards one side have no power over water that may find its way into the ship in the case of a steady or permanent list. The water lies in the lee bilge and forms a powerful inclining element. It often cannot be effectively dealt with, either because there are not sufficient pump suctions at the bilges, or because the suctions get choked with grain. One of the most valuable regulations made by bodies who exercise an influence over the loading of these vessels, is that means are to be provided for getting down through the cargo to the pump suctions in order to enable them to be cleared at any time. It is often as important that this should be done at the suctions in the bilges, as at the ordinary suctions near the middle line, though the difficulty is there very great. Lloyd's Register Society pay special attention to the arrangement of pump suctions and of sluice valves in all ships classed by them.

The conclusion, which must necessarily follow from an unbiassed examination of the cases of steamers laden with wheat cargoes that were lost during the years 1881, 1882, and 1883 is, that many of those losses would not have happened if the vessels had been so constructed, or so laden, as to have had a greater amount of stability to counteract the heeling effect of cargo that has a tendency to shift; or if the cargo could have been so secured that no shifting would have been possible. This is quite independent of the mere height of freeboard, which is obviously insufficient in at least two cases, irrespective of the question of stability.

We now come to grain-laden vessels that were lost during the same years, whose cargoes consisted of maize; and we only find one thus laden. She is described in Appendix D, Table I.(*b.*) p. 84. This is a vessel which foundered, and of whose loss we know the particulars. Her dimensions were 260·2 ft. × 34·0 ft. × 23·9 ft., and her freeboard was 4 ft. 9 ins. Maize is a cargo of approximately the same density as wheat; so that we here have a vessel similar in type and proportions to the wheat-laden vessels already described, and similarly laden; and the stability of which should possess similar characteristics. The history of the loss is practically a repetition of what has already been described. A heavy sea was shipped, which smashed in deck-houses and skylights, and found its way into the engine room and stoke-hold. Other seas followed, tearing ventilators off, and pouring into the engine room and holds. The ship lay with a heavy list to starboard, which the master attributed to water in the bilges, and not to shifting of cargo. She broached to, and fell over to port, her lee rail being under water. The pumps were choked, and the engines ceased to work. The list increased every hour, and the vessel was finally abandoned. In this maize-laden steamer we thus have the same state of things as in the wheat-laden steamers already described; and the same remark applies to her as to them, viz., that if she had possessed greater stability, her loss might probably have been prevented.

We next come to eight steamers laden with barley, that are described in Table I.

(*c.*) Out of those eight vessels, four foundered and left survivors; and four were lost with all hands. One of the first-named four was a vessel of similar proportions to the narrow three-deck class—251·5 ft. × 32·0 ft. × 21·1 ft. We also have particulars respecting one of that class, which is in the list of missing ships. Her dimensions were 267·0 ft. × 34·2 ft. × 22·7 ft. Both vessels showed themselves very tender at the commencement of their voyages, and one took a heavy list to port and went down. There is little doubt that the other shared the same fate; and we may reasonably infer that two of the other missing vessels, of which we have no particulars, may also have been lost through instability. Their dimensions were 260·0 ft. × 34·0 ft. × 23·1 ft., and 265·3 ft. × 33·1 ft. × 22·9 ft. Another of the vessels that foundered, whose dimensions were 189·4 ft. × 24·5 ft. × 18·4 ft., was lost through being struck by a sea which gave her a list to starboard. The list went on increasing, several seas broke on board and poured below in large quantities; the vessel continued to acquire a heavier list, till the starboard covering board became level with the water. She was gradually sinking when abandoned. As regards the vessels laden with barley cargoes, there appears to be therefore, no reason to doubt that if greater stability had been given to them, some of the losses might have been prevented. It is easier to make ships of this class safe with cargoes of barley than with cargoes of wheat, because the density of wheat is about 30 per cent. greater than that of barley, and they are, therefore, not so deep when laden with barley as when laden with wheat. This affords more scope for the use of water ballast; and there is no reason why ships of this class, when laden with barley, should not be made sufficiently stable by a proper use of water ballast tanks. If, instead of doing that, the ship is brought to a deeper draught with cargo carried in erections upon the deck, the danger may become even greater than if she were laden with a full wheat cargo.

A vessel of this class would usually have a fairly large freeboard when completely filled with barley, and this is probably sometimes thought to be all that is requisite for safety. The centre of gravity will, however, occupy a high position in the ship and the metacentre will generally be lower than if the vessel were more deeply laden. The righting moments at moderate angles of inclination may therefore be small, and the vessel may heel to a larger angle with a given shift of cargo than if laden with wheat to a deeper draught. This is illustrated, as has already been pointed out, by the curves A and B, in Fig. 1. And this may help to explain the otherwise strange circumstance that the number of losses of vessels laden with barley is only one less during these three years than that of vessels laden with wheat; although the vessels engaged in carrying barley, particularly on trying voyages, bear only a very small proportion to those that carry wheat. The safety of vessels laden with full cargoes of barley might be very largely increased by a proper use of water ballast, although the freeboard might thereby be reduced. There is nothing to show that thr best use was made of the water ballast in the cases described in the Tables.

The next grain cargo is rye and peas, and it will be seen by reference to Table

I. (*d*) that one vessel was lost when laden with it. She was one of the three-deck class already referred to, her dimensions being 275·8 ft. × 34·0 ft. × 24·0 ft. Her cargo was one, however, that could be stowed so as to give a much lower position of centre of gravity, and greater stability, than a full wheat cargo, the density of peas being much greater than that of rye; and the cargo was doubtless so stowed in this instance, with the heavier portion at the bottom and the light at the top. This vessel was laden down to a freeboard of 5 ft. 1 in., and was lost by sheer stress of weather. After battling with heavy gales in the North Atlantic during 11 days, till the whole of the deck fittings were swept away, the rudder was gone, the boilers were working loose and the hull began to show signs of straining, the vessel never exhibited any tendency to take a permanent list; and there is no reason to suppose that her loss was accelerated by instability.

One steamer was lost that was laden with cotton seed. She was ruled to be overladen.

The other grain-laden steamers lost during these three years were two in number, one being laden with a cargo of mixed grain, and one with grain the description of which is not known. The first named vessel was of the narrow three deck type, her dimensions being 246·5 ft. × 32·9 ft. × 23·3 ft., and she was laden with a full cargo. This vessel passed within 300 yards of another in the Bay of Biscay during a hurricane. Shortly afterwards a violent squall struck the two ships, and she was lost sight of. On the squall clearing away she was nowhere to be seen. It seems very probable that this vessel also heeled over and foundered.

We now come to Table II., Appendix D., which contains a list of 47 steamers laden with coal, that were lost during the five years 1881 to 1885. 33 of these were lost during the three years we are dealing with—1881 to 1883 The number is very large, but it must be remembered that the coal-carrying trade is one of enormous proportions. The average quantity of coal exported per annum during those three years was about 20,000,000 tons. And, although it is not known how much of that was carried in British, and how much in foreign ships, it must be obvious that the quantity of coal carried on over-sea voyages by British ships must have been very great. About two-thirds of that quantity was also carried, in addition, coast-wise; and all British steamers, of over 300 tons gross register, employed in the coasting trade, that were lost outside rivers or harbours, are included in these tables. Coal is a cargo which is beset by a variety of dangers. It may cause an explosion by reason of the gas generated after it is put on board; it may ignite spontaneously, and cause the destruction of the ship by fire; or, it may give the ship a dangerous list by shifting to one side in bad weather. It is also liable to choke the pumps with small coal and dirt, and thus make it impossible to clear water out of the ship. The losses from explosion and from spontaneous combustion now appear to be fewer than formerly. Explosions can be kept down by a good system of surface ventilation; and there appears to be little danger of explosive gas being generated after the coal has been three or four days on board.

Loss from spontaneous combustion can hardly occur except on the longest voyages. The known losses from those causes are included under the head of "other causes," in Appendix A, Item 6. There was one known loss of a steamer from spontaneous combustion of coal during the three years 1881 to 1883, and 22 sailing vessels. The precautions adopted for the prevention of explosion sometimes appear, however, to cause danger in other directions. For instance, the ventilators that are fitted on deck, particularly those often placed near the front of the bridge house in well-deck steamers, are liable to be carried away by heavy seas, and are sometimes difficult to close effectually in bad weather, as in the well-known case of the "Matador;" though in her case there was no apparent reason why there should have been anything to be carried away, as she was loaded with iron ore and did not require to have the ventilators shipped in place at all during that voyage. See Appendix D, Table III., p. 96. This is a mere mechanical difficulty, however, which might easily be overcome by making the deck fittings stronger, or by placing the more exposed of the ventilators in positions where they are protected, such as inside the bulkhead of the bridge house in well-deck steamers. It would appear by looking down the list of vessels in Appendix D, Table II., that some of them were lost, or had their loss facilitated in this way. There also appears to be a further danger in connection with the efficient surface ventilation of coal. Such ventilation can only be obtained by leaving a space between the top of the coal and the deck, through which air may circulate freely from end to end of the hold. The space thus left constitutes an element of danger, as it admits of a quantity of coal falling over to one side when there is a tendency to shift.

Out of the 33 coal-laden ships that were lost during these three years, 24 went down with all hands, so that it is only possible to know of the circumstances connected with the losses of the remaining nine. As regards those nine, inquiries were only held respecting six, and our information is practically restricted, therefore, to six cases. Two of the losses that were inquired into appear to have been caused by leaks arising at sea, the sources of which could not be discovered. The pumps were more or less inoperative in each case, through becoming choked with small coal and coal-dirt. In another instance, a sea was shipped which did considerable deck damage, smashed in skylights, carried away a ventilator to the main hold, and sent water below in large quantities. The vessel took a heavy list to starboard, the hole in the deck could not be effectively plugged, and she was finally abandoned. Another vessel was so laden as to be obviously unstable; she took a list to port, while steaming easy head to wind, and could not be righted. After being abandoned she was seen to take a sudden heel and go down, about two or three hours after the time of the first inclination. In the next case the water got below through a ventilator being carried away by a sea that broke upon the well-deck. The hole was afterwards stopped, the weather moderated, and the pumps appear to have acquired command of the water in the hold, but she was abandoned. She was ruled, however, by the inquiry court to have been prematurely abandoned.

This is all the specific information we have respecting the losses of the 33 coal laden ships under consideration. Inquiries were held respecting many of the cases of missing ships; but, as a rule, the only conclusion arrived at was that there was no evidence to show the probable cause of loss. We have much less information respecting the manner in which coal-laden ships are known to have been lost, than in the case of ships laden with grain. All that can be done therefore is to exhibit the facts so far as they are known, and leave them to tell their own tale.

We now come to steamers laden with metals and metallic ores, particulars of which will be found in Appendix D, Table III. There are only six of these. Four out of the six went down with all hands, and the other two foundered without drowning the crews. One of the two last named ran short of coals, and was left to drift helplessly before the wind. Several feet of water accumulated in the holds, and she was abandoned. The other vessel met with a hurricane soon after sailing, and her cargo, which consisted of steel rails, shifted over to one side, so that she had to be abandoned.

Time will not admit of any further comment upon these vessels, nor upon the steamers laden with other cargoes, that are described in Tables V. and VI. of Appendix D. The leading facts respecting them will be found noted in the columns of remarks that form part of the tables. It will be observed, however, that no steamer was lost while in ballast, during the three years under consideration.

Referring to Appendix B, Table IV., it will be seen that the Tables in Appendix D, that we have just dealt with, contain particulars of all the vessels included in the column headed steamers. The adjacent columns in that table relate to sailing ships; and similar details to those already given for steamers will be found, for iron sailing ships, in Appendix E. The particulars of the losses of those sailing ships are stated in the columns of remarks in the tables, so far as they are known, and I am not able now to add much to them. There are several points brought out, however, that appear worthy of notice. Out of the thirteen grain-laden sailing ships that were lost, eleven were laden with wheat and one with rice. The whole of the thirteen went down with all hands, except one vessel. In the case of that vessel, the only one respecting whose loss there is any direct evidence, we find she was thrown upon her beam ends in a hurricane, the cargo shifted, water got below among the grain, the pumps ultimately became choked with grain, and the vessel had to be abandoned.

Out of the sixteen iron sailing ships laden with coal, eleven went down with all hands; leaving five from which there were survivors. Inquiries were held in three out of those five cases; so that we only know the particulars of loss with reference to three out of the whole sixteen coal-laden vessels. It is a notable fact in connection with those three losses, that each appears to have been due to the shifting of cargo in bad weather.

With reference to the four iron sailing ships lost while in ballast, which will be found in Table VII. of Appendix E, p. 114, it will be observed that three were lost with all hands; and, consequently, we only know the circumstances in the case of the remaining one. In that instance, the loss was officially attributed to the indiscretion of the master, in throwing ballast overboard, in an open roadstead, while being towed. The vessel was capsized by a squall. It is quite possible that certain large sailing ships, when floating light, may have small righting moments at large angles of inclination, and may not be difficult to capsize at sea. Their case is different from that of steamers when light, because the latter always have the weights of boilers, machinery, and a certain quantity of coals in them; and either water ballast in the bottom or ballast in the hold. The heeling effect of sail is also much less in steamers than in sailing ships, because of the comparatively small quantity of sail they carry. We do not know the precise particulars of the ballasting of the other three sailing vessels that are missing; but it is quite possible that, although they may have appeared to be stiff at small angles of inclination, they were deficient in stability when heeled at sea under the action of a strong beam wind. Or, the ballast may have shifted, as it is capable of doing as sometimes stowed.

Returning to Appendix B. Table IV., it will be seen that the classes of ships that have not already been noticed, or dealt with in Appendices D and E, are wooden and composite sailing ships. There were 127 wooden sailing ships, and 779 lives in them, lost during the three years 1881–83, so that they constitute an important factor in the general question of losses at sea. There were also 9 composite sailing ships lost during that time and 101 lives in them. It is impossible to extend this Paper so as to include a detailed examination of all those cases, and I would only now point out, with reference to them, that it appears to be rather to the age and quality of many of the vessels we should look for the causes of loss, than in other directions. For instance, in the case of vessels laden with timber, which I have already called attention to, those lost were on an average 23 years old; and their general condition may be inferred from the fact that two-thirds of the number were unclassed in any register society. The same remark practically applies to the wooden sailing ships that were lost in ballast.

The object of this Paper is to present the known facts respecting recent losses in a manner that may help to show how they apply to different classes and varieties of ships. The chief difficulty in dealing with the subject is want of facts, and if more could be done towards making known the particulars of losses greater good would probably be effected than in any other way. The reports of the Wreck Inquiry Courts are useful, so far as they go, in this direction, though even in that respect they are not all that might be wished. In saying this I refer merely to the statements of fact they contain. I need hardly add that the opinions expressed upon the facts in the rulings of those courts are often imperfect or erroneous where difficult technical points are involved. This probably arises from the perfunctory character of many of the inquiries; and it has been explained by the Wreck Commissioner that the number of inquiries, and

the distant places at which they are sometimes held, often make exhaustive inquiries impossible.

It must strike anyone who looks carefully through the tables of losses in Appendix D that one of the most important points in connection with the foundered and missing ships we are considering, is unquestionably the small amount of stability with which steamers sometimes go to sea when fully laden. The safety of these ships often depends absolutely upon how much space is left unfilled with cargo in the 'tween decks. Experience usually fails to give any definite information in the matter except by the loss of the ships in which too little of such space has been left unfilled.

Let us consider for a moment what is the real state of things in a steamer laden with a cargo of grain or coal that does not completely fill the compartments in which it is carried. An attempt has been made to illustrate this in Fig. 2 (Plate X.). The curve A is the curve of righting moments for a three-deck steamer 282·8 ft. by 35·3 ft. by 24·2, with empty water ballast tanks in the holds, and with the holds and 'tween decks completely filled with homogeneous cargo up to the deck. The curve B is the curve of righting moments for the same vessel, with the same cargo, but with the cargo in the hold settled down one foot below the under surface of the main deck, and the cargo in the 'tween decks settled down six inches below the under surface of the upper deck. The centre of gravity of the cargo will be lowered by this subsidence; and the effect thus produced upon the stability is shown by the enlargement of the curve A into the curve B. Although the curve B shows, upon the face of it, a much larger and safer amount of stability than the curve A, there is an essential difference between the conditions in the two cases that is not disclosed by the curves, but that requires to be taken into account in judging of the safety of the vessel. In the case represented by the curve A the compartments are quite full, the cargo cannot shift, and, whatever inclination the ship may take, the centre of gravity of the cargo will remain fixed in position.

The case represented by the curve B is, however, quite different. The empty spaces between the upper surface of the cargo and the under side of deck, there admit of cargo falling over towards the lower side as the ship inclines, and, consequently, of the centre of gravity of the cargo moving over in the same direction. If the cargo were frictionless the upper surface would move over parallel to the surface of the water during inclination; and when it is not frictionless, it tends to move in that direction, and is liable to settle down approximately into that position when a vessel is held over to one side and is labouring in a seaway. The curve C shows the heeling moments that would be caused by the shift of such a cargo, supposing that at any angle of inclination the upper surface of the cargo were parallel to the water surface. In this case the curve C of heeling moments, due to the shifting of cargo, lies entirely outside the curve of righting moments B; and the vessel when so laden would be dependent entirely upon the friction of the particles of cargo among themselves and against the interior of the hull for safety against capsizing. If the cargo were frictionless the vessel would instantly capsize. In other words, the equili-

brium of the vessel in the upright position is unstable, except so far as stability is furnished by the friction of the cargo.

But the shifting of a cargo that does not completely fill a vessel does not always tend to capsize her. The curves of righting moments A and B are very small even for steamers of the type to which this vessel belongs, small as their stability sometimes is. The maximum righting lever given by curve A is 2 inches, and that given by curve B is 3 inches. The stability of these vessels is usually more than is here represented, and when that is the case the curve B often crosses the curve C, and passes outside of it at an angle of inclination of something like 25° or 30° deg. But up to that angle the curve C lies outside the curve B. That means that the shifting of cargo would heel the vessel over to the point at which the two curves cross, and that she would rest in equilibrium at that inclination. The excess of heeling moments over righting moments to the left of that point would prevent her returning to the upright position, and the excess of righting moments over heeling moments to the right of that point would prevent her going farther over. The effect of the shifting of water in the bottom towards one side is of a similar character. It tends to incline the vessel to a certain angle, but no farther; on the other hand, it resists further inclination. That angle is, of course, the one at which the centre of gravity of the water, which at the commencement of inclination falls outside the vertical line through the centre of buoyancy, coincides with that line. It is usually, perhaps, at about 30° to 40° of inclination. The tendency of water in a comparatively flat-bottomed ship is to bring its centre of gravity into the lowest possible position below the water surface by lowering the bilge, and to remain there. Its action may be practically illustrated by pouring water into a rectangular box, floating upright in stable equilibrium. The effect will be to make one of the lower edges, or bilges, take the lowest position by the inclination of the box.

The effect of shifting that is illustrated by the curve C is that due to cargo which is not secured by shifting boards. Coals are not usually so secured, so that this curve would show the heeling moment at any angle to which the cargo might settle if it consisted of coal. In the case of grain, which is secured by middle line shifting boards of the whole depth of the compartments, this curve would be considerably reduced in size. It will be observed, however, that the extent of shifting is only reduced by shifting boards; a certain amount of shifting still remains possible. Roughly speaking, the heeling moments caused by shifting when there are middle line shifting boards would be one-fourth of what they are when there are none.

The object of these remarks is to show that the tendency of a homogeneous cargo which shifts, and of water in the hold of a vessel, is often not to completely capsize her, but to cause her to lie over upon one side with the bilge in approximately the lowest position it can find, like a rectangular box floating with one of its edges downwards. Neither the cargo nor the water may tend to carry the vessel over beyond a certain angle; but, on the other hand, they may resist further inclination. From this it follows that, in studying to give many of these ships sufficient stability to make them safe in the event fo cargo shifting, or

of water getting into the hold, we need only deal with the early part of the curve of stability, say, up to 30° or 40° of inclination. It is initial stiffness, or stiffness at moderate angles of inclination, that is required to resist the heeling effect of shifting cargo or of water. At large angles the shift of cargo or of free water would often act in the direction of restoring the vessel towards the upright position, not of moving her farther away from it.

A reference to the cases described in the columns of remarks in Appendix D will show that none of the vessels that heeled, and had to be abandoned, were seen to capsize. They all lay over at a considerable angle, with the lee covering board under water, or the lee rigging in the water, and went down in that position. These vessels apparently do not capsize. They heel over towards an inclined position of stable equilibrium, accumulate water in the lee bilge, and sink.

The value of shifting boards is sufficiently obvious in the case of grain laden vessels. It is only a question whether, considering the number of coal laden vessels that shift their cargoes, heel over and founder, shifting boards ought not to be fitted also in vessels carrying coal. But the most effective precaution that can be taken with reference to all these vessels, is to have their stability, and the safe limits of loading, determined by calculation before they are sent to sea. It may thus be ascertained in each case, for the different descriptions of cargo proposed to be carried, what space must be left unfilled in the 'tween decks, when the cargo is of too great density to fill the vessel; what weight of ballast, if any, will be required in the bottom, when the vessel is completely filled with a cargo too light to bring her to her load line; or, what combination of empty spaces in the 'tween decks and ballast in the bottom will enable the greatest weight of cargo to be carried with safety. Besides this, it should be ascertained what effect the consumption of coal at sea may have upon stability, and what further allowances may be requisite on that account.

It is a remarkable feature of the tables for iron sailing ships in Appendix E, that out of 13 vessels laden with grain that were all lost, none of the crew were saved except from one vessel. This seems to point to a kind of loss that leaves no time for saving life. Capsizing would be a loss of such a character; and these ships would be in danger of capsizing suddenly, or being thrown upon their beam ends and foundering, through the combined effects of a heavy shift of cargo and a pressure of wind upon the sails in bad weather. The ships that were lost were all laden with wheat except one, and she was laden with rice. These cargoes, which measure about 46 cubic ft. per ton of weight, would not be nearly sufficient to fill them, as many sailing ships of large size could only float at a proper draught when filled with cargo measuring about 60 cubic ft. per ton of weight. In the case of the vessels that were lost, there must either have been large empty spaces between the surface of the cargo and the deck, or else the cargo must have been held up to the deck in a reduced space made by fitting temporary bulkheads at the ends. The shifting of cargo, if there were large empty spaces originally left, or if a temporary bulkhead put up to confine it gave way while the vessel was labouring at sea, might account for some of these disasters; and this seems to be a matter worthy of attention. The loose

stowage of coal in some sailing ships may also be a cause of loss when they are thus laden.

The magnitude of the subject has caused the length of this Paper to extend far beyond what I first intended, and, at the same time, it has prevented me from touching upon more than a few of its leading features. I will bring these remarks to a close, however, with a statement of certain points that appear to be suggested by the foregoing considerations.

1. The shifting of cargoes is one of the chief causes of the foundering of steamers and iron sailing ships at sea, independently of mere depth of loading.

2. Dangerous shifting of grain sometimes takes place, through hasty and imperfect stowage, inefficient shifting boards, or weakly constructed end bulkheads, or through the omission to fit end bulkheads where such are required on account of the density of the cargo; and dangerous shifting of coal sometimes takes place, because it is carried in compartments that are not fitted with shifting boards.

3. Many steamers carrying grain and coal cargoes—notably the class of narrow three-decked steamers built several years ago—are vessels that have insufficient stiffness when fully laden, to resist heeling to a dangerous angle in the event of cargo shifting, or of water getting below.

4. The effect upon such vessels of the shifting of cargo, and of water below, is generally to hold them over at a considerable angle of inclination, but not to completely capsize them.

5. Pumping power at the bilges is often an essential condition of preventing loss in such circumstances, and of getting a vessel righted.

6. The stability of these vessels, when laden with the various cargoes they are likely to carry, should be completely determined by calculation before they are sent to sea; and clear instructions, based upon the information so obtained, should be framed for the guidance of those responsible for their loading. Such instructions should include particulars of the empty spaces to be left in the 'tween decks, or the weight of ballast to be carried, or both, for each class of cargo.

7. All the authentic particulars procurable of ships that have foundered and are missing, and of the circumstances and the manner in which the foundered ships were lost, should be collected and published periodically, for the information of the shipping community.

8. The losses of steamers through the shifting of cargoes seem to be chiefly among the narrow steamers of the three-decked type that were built several years ago. The steamers of that type that have recently been built have more beam and greater stability than those formerly built; and it may be confidently hoped that the attention which has been given to the matter of late, and the improvements which have consequently been introduced into this type of vessels will lead to a diminution of losses among them.

APPENDIX A.

TABLE SHEWING THE TOTAL LOSSES OF BRITISH SHIPS DURING THE 3 CALENDAR YEARS 1881 TO 1883, AND THE NUMBER OF LIVES OF MASTERS AND SEAMEN LOST THEREBY.

DESCRIPTION OF SHIPS.	1881.		1882.		1883.		Total for 3 years.		Remarks.
	No. of Ships.	Lives.	No. of Ships.	Lives.	No. of Ships.	Lives.	No. of Ships	Lives.	
1. FOUNDERED and MISSING SHIPS, registered in the United Kingdom, *of and above* 300 *tons gross register*, lost at sea . — Laden with grain . . .	21	286	13	205	10	178	44	669	
" coal . . .	25	266	26	231	35	536	86	1033	
" metals and metallic ores	2	...	6	69	5	80	13	149	
" timber . . .	25	155	3	18	10	113	38	286	
" other cargoes . .	17	155	13	95	15	141	45	391	
" general cargoes . .	8	162	12	138	5	74	25	374	
In ballast	5	45	4	32	4	27	13	104	
Cargoes unknown . . .	...	...	...	...	...	...	...	...	
Total . . .	103	1069	77	788	84	1149	264	3006	
2. FOUNDERED and MISSING SHIPS, registered in the United Kingdom, *below* 300 *tons gross register*, lost at sea (no fishing vessels) — All cargoes. .	146	490	94	242	104	298	344	1030	
3. FOUNDERED and MISSING, all ships registered in United Kingdom, lost at sea (no fishing vessels)	249	1559	171	1030	188	1447	608	4036	
4. COLLISIONS " "	61	99	57	84	40	76	158	259	
5. STRANDINGS " "	426	573	345	329	342	342	1113	1244	
6. Losses from OTHER CAUSES "	44	9	30	29	29	22	103	60	
7. The whole number of British Ships, registered in the United Kingdom, lost from all causes at sea (no fishing vessels) .	780	2240	603	1472	599	1887	1982	5599	See Table VII. p. 58.
8. Fishing Vessels, *registered in the United Kingdom*, lost at sea	97	233	72	196	122	430	291	859	Difference between Tables V. and VII. pp. 57 & 58.
9. UNREGISTERED SHIPS of all classes, belonging to the United Kingdom, lost at sea.	96	264	57	52	55	49	208	365	
10. Registered and Unregistered Ships of all classes, *belonging to the Colonies*, lost from all causes at sea	365	489	373	343	372	305	1110	1137	Do. Tables III. & V. pp. 55 & 57.
11. Registered and unregistered ships of all classes belonging to the United Kingdom and the Colonies, *lost in rivers and harbours*	49	52	44	15	58	21	151	88	Do. Tables I. & III. pp. 54 & 55.
12. The whole number of British Ships (*i.e.*, belonging to the United Kingdom and the Colonies) wrecked or totally lost from all causes, and the number of lives lost thereby .	1387	3278	1149	2078	1206	2692	3742	8048	See Table I. p. 54.

APPENDIX B.

TABLE I.

FOUNDERED AND MISSING SHIPS REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE CALENDAR YEAR 1881. (103 SHIPS AND 1,069 LIVES LOST.)

CARGO.		Steamers.		Sailing Ships.						Totals.				Grand Total.	
		All Iron.		Iron.		Wood.		Composite.		Steamers.		Sailing Ships.		All Ships.	
		Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.
Grain	Wheat	4	54	4	96	3	11	...	...	4	54	7	107	11	161
	Maize	1	...	...	...	1	...	...	...	1	...	1	...	2	...
	Barley	4	71	...	...	...	...	...	...	4	71	...	...	4	71
	Rye & Peas	1	...	...	...	...	...	...	...	1	...	...	...	1	...
	Oats	1	23	...	...	...	...	...	...	1	23	...	...	1	23
	Rice	...	...	1	21	...	...	...	...	...	...	1	21	1	21
	Not stated	...	...	1	10	...	...	...	...	...	...	1	10	1	10
Grain of all kinds		11	148	6	127	4	11	...	...	11	148	10	138	21	286
Coal		10	146	3	29	11	67	1	24	10	146	15	120	25	266
Metals		...	...	1	...	1	...	...	...	...	...	2	...	2	...
Timber		...	...	...	...	25	155	...	...	...	...	25	155	25	155
Other		2	17	3	36	10	79	2	23	2	17	15	138	17	155
General		3	70	3	80	2	12	...	...	3	70	5	92	8	162
In ballast		...	...	1	35	4	10	...	...	...	...	5	45	5	45
Unknown		...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total		26	381	17	307	57	334	3	47	26	381	77	688	103	1,069

TABLE II.

FOUNDERED AND MISSING SHIPS REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE CALENDAR YEAR 1882. (77 SHIPS AND 788 LIVES LOST.)

CARGO.		Steamers.		Sailing Ships.						Totals.				Grand Total.	
		All Iron.		Iron.		Wood.		Composite.		Steamers.		Sailing Ships.		All Ships.	
		Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.
Grain	Wheat	4	98	1	22	1	16	...	...	4	98	2	38	6	136
	Barley	3	40	...	...	...	...	...	...	3	40	...	...	3	40
	Rice	...	...	...	...	2	14	...	...	..	...	2	14	2	14
	Beans	...	...	...	...	1	15	...	...	...	...	1	15	1	15
	Not stated	1	...	...	...	...	...	...	...	1	...	...	...	1	...
Grain of all kinds		8	138	1	22	4	45	...	...	8	138	5	67	13	205
Coal		8	85	7	107	11	39	...	...	8	85	18	146	26	231
Metals		3	22	2	47	1	...	...	...	3	22	3	47	6	69
Timber		...	...	...	...	3	18	...	...	...	...	3	18	3	18
Other		1	...	1	16	11	79	...	...	1	...	12	95	13	95
General		6	111	2	27	4	...	...	...	6	111	6	27	12	138
In Ballast		...	...	1	19	3	13	..	...	...	...	4	32	4	32
Unknown		...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total		26	356	14	238	37	194	...	...	26	356	51	432	77	788

APPENDIX B—*Continued.*

TABLE III.

FOUNDERED AND MISSING SHIPS REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE CALENDAR YEAR 1883. (84 SHIPS AND 1,149 LIVES LOST.)

CARGO.	Steamers.		Sailing Ships.						Totals.				Grand Total.	
	All Iron.		Iron.		Wood.		Composite.		Steamers.		Sailing Ships.		All Ships.	
	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.
Grain. Wheat	1	28	6	103	...	...	...	...	1	28	6	103	7	131
Grain. Barley	1	...	...	...	...	...	...	...	1	...	...	...	1	...
Grain. Cotton Seed	1	22	...	...	...	...	...	...	1	22	...	...	1	22
Grain. Mixed (maize, wheat, barley, oats, &c.)	1	25	...	...	...	...	...	...	1	25	...	...	1	25
Grain of all kinds	4	75	6	103	...	...	...	...	4	75	6	103	10	178
Coal	15	302	6	118	12	97	2	19	15	302	20	234	35	536
Metals	3	42	1	38	...	...	1	...	3	42	2	38	5	80
Timber	...	...	...	...	9	94	1	19	...	...	10	113	10	113
Other	3	65	1	...	9	60	2	16	3	65	12	76	15	141
General	4	74	...	...	1	...	...	...	4	74	1	...	5	74
In Ballast	...	...	2	27	2	...	...	...	...	...	4	27	4	27
Unknown	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total	29	558	16	286	33	251	6	54	29	558	55	591	84	1,149

TABLE IV.

FOUNDERED AND MISSING SHIPS REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE THREE CALENDAR YEARS 1881 TO 1883 (264 SHIPS AND 3,006 LIVES LOST).

CARGO.	Steamers.		Sailing Ships.						Totals.				Grand Total.	
	All Iron.		Iron.		Wood.		Composite.		Steamers.		Sailing Ships.		All Ships.	
	Lives.	Ships.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.
Grain. *a.* Wheat	9	180	11	221	4	27	...	...	9	180	15	248	24	428
Grain. *b.* Maize	1	...	...	...	1	...	...	...	1	...	1	...	2	...
Grain. *c.* Barley	8	111	...	...	...	...	...	...	8	111	...	...	8	111
Grain. *d.* Rye & Peas	1	...	...	...	...	...	...	...	1	..	...	...	1	...
Grain. *e.* Oats	1	23	...	...	...	...	...	...	1	23	...	...	1	23
Grain. *f.* Rice	...	...	1	21	2	14	...	...	...	...	3	35	3	35
Grain. *g.* Beans	...	...	...	...	1	15	...	...	...	...	1	15	1	15
Grain. *h.* CottonSeed	1	22	...	...	...	...	...	...	1	22	...	...	1	22
Grain. *i.* Mixed	1	25	...	...	...	...	...	...	1	25	...	...	1	25
Grain. *k.* Not stated	1	...	1	10	...	..	...	...	1	...	1	10	2	10
I. Grain, all kinds	23	361	13	252	8	56	...	...	23	361	21	308	44	669
II. Coal	33	533	16	254	34	203	3	43	33	533	53	500	86	1033
III. Metals	6	64	4	85	2	...	1	...	6	64	7	85	13	149
IV. Timber	...	...	...	...	37	267	1	19	...	...	38	286	38	286
V. Other	6	82	5	52	30	218	4	39	6	82	39	309	45	391
VI. General	13	255	5	107	7	12	...	...	13	255	12	119	25	374
VII. In Ballast	...	...	4	81	9	23	...	...	...	...	13	104	13	104
VIII. Unknown	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total	81	1295	47	831	127	779	9	101	81	1295	183	1711	264	3006

APPENDIX C.

TABLE I.

FOUNDERED AND MISSING SHIPS (*Steamers* AND *Iron Sailing Ships* ONLY) REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE TWO CALENDAR YEARS 1884 AND 1885. (24 SHIPS AND 589 LIVES LOST.)

CARGO.	1884.				1885.			
	Steamers.		Iron Sailing Ships.		Steamers.		Iron Sailing Ships.	
	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.	Ships.	Lives.
Grain: *a.* Wheat	...	...	...	...	2	31	2	25
Grain: *a.* Wheat & Maize	...	...	...	...	2	52	...	...
Grain: *f.* Rice	1	27	1	30	...	...	1	17
Grain: *i.* Mixed	...	...	...	...	1	24	...	...
I. Grain of all kinds	1	27	1	30	5	107	3	42
II. Coal	8	89	5	60	6	125	2	42
III. Metals	1	12	2	45	3	58	1	13
IV. Timber	...	...	...	...	...	...	...	...
V. Other	3	21	2	59	2	25	...	...
VI. General	1	23	1	3	2	56	4	102
VII. In Ballast	2	28	2	32	...	...	1	18
VIII. Unknown	..	...	..	...	...	...	...	...
Total for the 2 years	16	200	13	229	18	371	11	217

TABLE II.

FOUNDERED AND MISSING SHIPS (*Steamers* AND *Iron Sailing Ships* ONLY) REGISTERED IN THE UNITED KINGDOM, OF AND ABOVE 300 TONS GROSS REGISTER, WHICH WERE LOST AT SEA, AND THE LIVES OF MASTERS AND SEAMEN LOST THEREBY, DURING THE 5 CALENDAR YEARS 1881, 1882 1883, 1884 AND 1885. (187 SHIPS AND 3143 LIVES LOST.)

CARGO.	Steamers.		Iron Sailing Ships.	
	Ships.	Lives.	Ships.	Lives.
Grain: *a.* Wheat	11	211	13	246
Grain: *a.* Wheat & maize	2	52	...	...
Grain: *b.* Maize	1	...	...	...
Grain: *c.* Barley	8	111	...	...
Grain: *d.* Rye and Peas	1	...	...	...
Grain: *e.* Oats	1	23	...	...
Grain: *f.* Rice	1	27	3	68
Grain: *g.* Beans	...	...	...	...
Grain: *h.* Cotton Seed	1	22	...	...
Grain: *i.* Mixed	2	49	...	...
Grain: *k.* Not stated	1	...	1	10
I. Grain of all kinds	29	495	17	324
II. Coal	47	747	23	356
III. Metals.	10	134	7	143
IV. Timber	...	...	...	...
V. Other	11	128	7	111
VI. General	16	334	10	212
VII. In ballast	2	28	7	131
VIII. Unknown	...	...	...	...
Total for the 5 years	115	1866	71	1277

APPENDIX

DETAILED LIST OF STEAMSHIPS BELONGING TO THE UNITED KINGDOM OF AND ABOVE 300 TONS GROSS REGISTER, CALENDAR YEARS 1881, 1882,

TABLE I.—STEAMSHIPS LADEN WITH

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
												(*a.*) WHEAT
Foundered—1881.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Drumduff" . . 140 H.P.	2	260·9	32·4	22·8	24 1	9½	1,423	1,333	4 1	4 2	20 10	Philadelphia .
"Annie Arbib" . 150 H.P.	7	250·1	30·1	19·5	20 7	8½	1,160	1,076	4 6	4 9	16 11½	Cronstadt .
Missing—1881. "Saxon Monarch". 160 H.P.	3	270·0	33·5	24·0	22 5	10	1,840	1,659	3 9	3 11 to 4 2	...	Odessa . .
"Lockyer" 220 H.P.	New.	286·0	37·0	22·8	24 3	10	2,072	1,939	4 9	4 11	22 7½	Calcutta .
Foundered—1882. "Escambia" . . 210 H.P.	3	291·0	34·7	24·5	26 0	10	2,154	1,937	4 9	4 10	22 3	San Francisco
"Winton" 200 H.P.	2	271·0	35·8	23·5	24 9	10	1,913	1,772	3 8	3 2	22 6	Odessa . .
Missing—1882. "Dallam Tower" . 250 H.P.	2	285·0	35·2	24·5	25 10	10	2,055	1,927	4 2	...	...	New Orleans .
"Lord Nelson" . 200 H.P.	4	270·2	34·2	24·6	25 11	10	1,780	1,705	4 6	4 6½	...	Odessa . .
Missing—1883. "Inchclutha" . 225 H.P.	4	285·5	35·0	24·4	25 9	10	1,984	1,863	4 6	5 0	21 9	Calcutta .
Foundered—1885. "Benwell Tower" . 400 H.P.	1	320·0	42·4	18·4	22 2	nil.	3,090	3,097	5 6	7 0	...	Baltimore .

D.

WHICH HAVE BEEN REPORTED TO THE BOARD OF TRADE AS FOUNDERED AND MISSING, DURING THE FIVE
1883, 1884 AND 1885.

GRAIN CARGOES (29 Steamers).

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
(13 Steamers).							
		1881.					
Antwerp . .	N. Atlantic .	a. 15 Feb. . b. 3 March	24	...	1	...	Encountered succession of gales. Decks kept constantly filled with water; pumps became choked and useless by grain washing into limbers; vessel took heavy list to starboard, settled down fast, and was abandoned.
London . .	North Sea .	a. 16 Nov. . b. 28 Nov.	24	...	...	...	Shifting boards insufficient, and not properly secured. Cargo shifted from side to side. Vessel thrown at last by heavy sea upon starboard broadside, and could not be righted. Was then abandoned.
Antwerp .	Not known .	a. 8 Oct. . b. 22 Oct.	27	...	27	...	Not heard of after passing Gibraltar on the 22nd Oct. The freeboard appears to have been 3 ft. 11 ins. to 4 ft. 2 ins. on leaving Odessa. The Wreck Commissioner ruled the vessel overladen.
London . .	Not known .	a. 7 Nov. . b. 8 Nov.	26	1	26	1	Not heard of after passing the Sandheads, R. Hooghly, 8th Nov. The Wreck Commissioner ruled that she was very deeply laden on leaving Calcutta, and probably foundered in a cyclone.
		1882.					
St. Vincent .	San Francisco Bar	a. 19 June . b. 19 June	29	...	25	...	Engines slowed down, unknown to master, while crossing bar, through a dangerous sea. Deck filled with water, which passed into engine-room through an open door. Vessel careened over and could not be righted. She speedily sank.
Rotterdam .	Off Ushant .	a. 29 Oct. . b. 16 Nov.	25	...	24	...	The Wreck Commissioner ruled that she was overladen. Took a good deal of water on deck during hard gale. Water accumulated to leeward, and vessel took a list to starboard. Water continued to increase below till lee furnaces were put out. The lee rigging was then under water, and the crew abandoned the vessel. They had hardly left the ship's side before she went down.
Rotterdam .	Not known .	a. 7 Sept. . b. ...	25	...	25	...	Not heard of after leaving New Orleans. No inquiry held. Laden with 2,505 tons of wheat.
Antwerp .	Not known .	a. 10 Oct. . b. 23 Oct.	24	...	24	...	Not heard of after passing Gibraltar, 23rd Oct. Wreck Commissioner ruled that she was fully laden, but no evidence to show how she was lost.
		1883.					
Falmouth .	Not known .	a. 14 July . b. 28 Aug.	28	...	28	...	Not heard of after passing Gibraltar, 28th Aug. The Wreck Commissioner ruled that there was nothing to show how she was lost.
		1885.					
Liverpool .	N. Atlantic .	a. 20 Jan. . b. 29 Jan.	30 &	2 Stowaways.	2	...	This was a spar-deck vessel, with a freeboard of 7 feet to spar deck. She met with heavy weather, steering gear was carried away, and much deck damage done. The hull strained considerably, a cracking noise was heard amidships, water came into the stokehole and engine-room through the seams and butts of the plating, and, as the water continued to gain on the pumps, she was abandoned. This appears to be an instance of a spar-deck vessel becoming unseaworthy through straining when laden unduly deep.

APPENDIX

TABLE I.

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
Missing—1885.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Fernwood" . . 20 H.P.	7	280·0	34·2	24·7	...	...	1,852	1,780	5 1	6 2	...	New York .
"Preston" 300 H.P.	3	300·0	40·0	24·5	25.11	9½	2,539	2,233	3 4	4 11	...	New York .
"Clandon" 200 H.P.	6	285·0	35·0	24·4	...	...	1,971	1,860	4 9	5 9	...	New York .
												(*b.*) MAIZE
Foundered—1881. "Belsize" 180 H.P.	3	260·2	34·0	23·9	25 2	9½	1768	1607	4 9	4 9	21 3	New Orleans .
												(*c.*) BARLEY
Foundered—1881. "Robin Hood" . 90 H.P.	9	207·3	28·5	17·0	17 9	8	815	731	1 10	...	...	Ibrail . .
"Calliope" 95 H.P.	20	251·5	32·0	21·1	22 1	9	1,450	1,140	2 6	2 6	...	Odessa . .
Missing—1881. "Antisana" . . 180 H.P.	1	267·0	34·2	22·7	25 1	9½	1,706	1,581	3 10	...	19 11	Odessa . .
"Morea" 140 H.P.	2	260·0	34·0	23·1	24 4	9½	1,648	1,493	4 6	...	...	Odessa . .
Foundered—1882. "Eunice" 60 H.P.	10	189·4	24·5	18·4	19 2	7	661	661	4 1½	4 4	15 0	Ystadt . .

D.—*continued.*

—*continued.*

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Bristol . .	Not known .	a. 20 Jan. . b. ...	25	...	25	...	Not heard of after sailing. Laden with 1,200 tons of wheat and maize, 1,053 tons of general provisions, and 247 tons bunker coal. Wreck Commissioner ruled that loss was probably due to collision with icebergs.
Avonmouth .	Not known .	a. 20 Jan. . b. ...	29	...	29	...	Not heard of after sailing. Laden with 2,560 tons wheat, 309 tons other produce, and about 370 tons bunker coal. Ruling as in case of "Fernwood."
Leith . .	Not known .	a. 24 Jan. . b. ...	27	...	27	...	Not heard of after sailing. Laden with 1,239 tons of wheat and maize, 1,155 tons of general provisions, 104 tons dunnage and stores, and 300 tons bunker coal. The Wreck Commissioner ruled as in the case of the "Fernwood."
(1 Steamer).							
Copenhagen .	N. Atlantic .	1881. a. 27 March b. 16 April	23	1	...	...	This vessel had no poop or raised cabin aft. She shipped a sea over stern which smashed in deck-houses, and cabin skylights, and found its way into engine-room and stokehold. Other seas followed, tearing ventilators off flush with deck and pouring in large quantities into the engine-room and holds. The ship lay with a heavy list to starboard, which the master attributed to water in the bilges and not to shifting of cargo. Ship broached to and fell over to port, the lee-rail being under water. The pumps were choked, and the engines ceased to work. The list increased every hour, and the vessel was finally abandoned.
(8 Steamers).							
Bremen . .	Near Ushant .	1881 a. 23 Sept. b. 14 Oct.	17	...	...	...	No inquiry held. Laden with 950 tons of barley.
Bremerhaven .	Off Portugal .	a. 4 Oct. b. 22 Oct.	22	6	21	6	Took slight list to starboard in Black Sea, which was cured by retrimming cargo at Constantinople. Between entrance to Tagus and the Burlings took a heavy list to starboard with heavy sea on port quarter. Vessel was hove to; but wheel chains broke, and vessel took a heavy list to port. She failed to answer her helm, and soon went down. The Wreck Commissioner ruled her overladen and insufficiently provided with shifting boards. A portion of the cargo was stowed in the poop.
Limerick .	Not known .	a. 3 Nov. . b. 16 Nov.	27	...	27	...	Not heard of after passing Gibraltar, 16th Nov. Master wrote home that she was tender in the Black Sea. Was still tender the day before reaching Malta, even with ballast tanks under engine-room filled and yards sent down. Mr. Raffles ruled that more ballast should have been carried with a full cargo of barley. Laden with 2,054 tons of cargo and 205 tons of bunker coal.
London . .	Not known .	a. 15 Nov. . b. ...	23	...	23	...	Not heard of after passing Constantinople, 15th Nov. No inquiry held. Laden with 9,783 qrs. grain and 1,994 bags of flour.
Waterford .	Near Horn Reef.	1882 a. 1 Dec. . b. 6 Dec.	15	...	...	...	Vessel struck by heavy sea, which broke on board. Head brought to wind and sea, when it was observed she had a list to starboard. Gale and sea increasing, several seas broke on board, doing great damage and pouring below in large quantities. Vessel continued to acquire a heavier list, and sprang a bad leak aft. Starboard covering board became level with water, and the ship was gradually sinking when she was abandoned. The shifting boards only extended 5 feet below the deck.

APPENDIX

TABLE I.

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
Missing—1882.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Cosmo" 150 H.P.	3	265·3	33·1	22·9	24 0	9½	1,545	1,472	4 0	...	...	Sebastopol .
"Abercarron" . 99 H.P.	4	205·3	28·9	17·8	18 11	8	835	747	3 0	...	...	Stettin . .
Foundered—1883. "Alfred" 100 H.P.	13	224·4	30·1	17·3	18 1	8	1,063	830	2 1	2 5½	16 9	Smyrna . .
												(*d.*) Rye and Peas
Foundered—1881. "Hurworth" . . 160 H.P.	3	275·8	34·0	24·0	25 4	10	1,937	1,751	4 4	5 1	...	Montreal .
												(*e.*) Oats
Missing—1881. "Norfolk" 96 H.P.	16	241·5	31·0	20·2	21 1	8½	1,255	1,197	3 4	...	...	Reval . .
												(*f.*) Rice
Missing—1884. "Charles Townsend Hook" 140 H.P.	7	240·0	33·1	20·8	...	...	1,390	...	...	...	...	Saigon . .
												(*g.*) Beans
												(*h.*) Cotton Seed
Missing—1883. "Bywell Castle" . 120 H.P.	13	254·3	32·1	19·6	20 7	9	1,376	1,168	2 2	2 3	...	Alexandria .

D—*continued.*

—*continued.*

Voyage. To	Where lost.	*a.* Date of sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
		1882					
Malta . .	Not known .	*a.* 31 Jan. . *b.* ...	24	...	24	...	Not heard of after sailing. Laden with about 1,688 tons of cargo. No inquiry held.
Leith . .	Not known .	*a.* 1 Dec. . *b.* 2 Dec.	16	...	16	...	Last seen off Elsinore, 2nd Dec. No inquiry held. Laden with 887 tons of cargo.
		1883					
Falmouth .	Off Cape Finisterre	*a.* 17 Jan. . *b.* 13 Feb.	20	1	...	...	Cargo settled and shifted to port soon after leaving Smyrna. It was retrimmed at Malta. After passing Gibraltar there was a strong beam wind and sea on port side. Master kept fore and aft sails set, and vessel gradually acquired a list to starboard, which went on increasing. Water continued to accumulate in the engine-room bilge, and vessel was repeatedly brought head to wind to enable it to be pumped out. The water kept gaining, however, in the engine-room, and the list increased. She was taken in tow by another steamer, but was finally abandoned full of water and on her beam ends.
(1 Steamer).							
		1881					
Rotterdam .	N. Atlantic .	*a.* 14 Nov. . *b.* 1 Dec.	25	...	...	...	Ruled by inquiry court at North Shields to be overladen. Got into a hurricane, 17th Nov. Ship made bad weather and shipped large quantities of water on deck, being at times completely flooded. Deck gear received much damage. Bad weather continued and much of the 'tween deck cargo was jettisoned. Gale came on with such fury on the 21st that ship was hove to seven days. Rudder was carried away, and seas broke on board with such force that ship became unmanageable. She was abandoned on the 1st Dec., with boats destroyed and gone, rudder lost, everything on deck swept away, boilers commencing to work loose, and hull showing signs of the severe straining that had taken place during the eleven days the vessel was in a helpless condition.
(1 Steamer)							
		1881					
Rouen . .	Not known .	*a.* 17 Dec. . *b.* ...	25	...	23	...	Not heard of after sailing. No inquiry held. Weight of cargo about 1,880 tons.
(1 Steamer)							
		1884					
Hong Kong .	Not known .	*a.* 18 Nov. . *b.* ...	27	...	27	...	Not heard of after sailing. No inquiry held. Weight of cargo not known
(Nil.)							
(1 Steamer)							
		1883					
Hull . .	Not known .	*a.* 15 Jan. . *b.* 29 Jan.	22	...	22	...	Not heard of after being seen near the Burlings on 29th Jan. The Wreck Commissioner ruled that the vessel was overladen, and probably foundered in a heavy gale in the Bay of Biscay.

APPENDIX

TABLE I.

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From.
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
												(*i.*) MIXED
Missing—1883. "Troubadour" . 150 H.P.	Years. 5	Ft. 246·5	Ft. 32·9	Ft. 23·3	Ft. Ins. 24 7	Ins. 9½	1,575	1,493	Ft. Ins. 4 5	Ft. Ins. ...	Ft. Ins. ...	Odessa . .
Missing—1885. "Standard" . . . 150 H.P.	10	271·7	33·8	23·4	25 3	...	1,661	1,576	4 6	5 6	...	Boston . .
												(*k.*) NOT STATED
Foundered—1882. "Curfew" 90 H.P.	5	200·9	29·0	15·7	16 6	7	815	648	2 0	...	...	Cronstadt
												TABLE II.—STEAMSHIPS LADEN WITH COAL
Foundered—1881. "Gosforth" 120 H.P.	15	244·5	29·2	17·4	18 4	8½	1,064	934	2 9	...	17 3	Newport, Mon.
"Pacha" 110 H.P.	26	190·4	26·2	14·6	15 5	7	632	520	2 5	2 5	See Note.	Burntisland .
"Countess of Durham" 80 H.P.	26	177·7	28·1	15·0	15 6	7	539	518	2 6	...	...	Sunderland .
Missing—1881. "Marathon" . . 140 H.P.	3	238·9	31·5	20·3	21 5	9	1,188	1,078	3 4	...	...	North Shields
"Ash" 120 H.P. .	2	240·5	34·0	18·6	19 9	9	1,421	1,146	1 8	...	...	Nagasaki .
"Charlton" 120 H.P.	12	233·4	29·0	23·4	24 3	8	1,218	1,217	5 4½	...	...	Newcastle, N.S.W. .
"Usworth" 80 H.P.	12	179·3	27·0	15·0	15 11	6½	547	488	2 0	...	...	Tyne . .
"Nile" 90 H.P. .	6	211·9	29·5	16·2	17 4	7	973	753	1 6	...	...	Newcastle-on-Tyne . .
"Tabor" 90 H.P. .	9	208·3	27·8	14·8	15 8	7	811	649	1 5	...	...	South Shields
"Lord Bute" 98 H.P.	13	204·7	28·2	16·2	16 11	7½	754	677	2 6	...	...	South Shields
Foundered—1882. "Marguerite" . 70 H.P.	10	180·0	25·0	14·0	14 7	7½	470	389	1 9	About 2 9	13 4½	Glasgow .

D—*continued.*

—*continued.*

Voyage. To	Where lost.	*a* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
(2 Steamers).							
Antwerp . .	Not known .	1883 *a.* 14 Aug. *b.* 1 Sept.	25	...	25	...	Laden with 2,082 tons of grain of different kinds, 108 tons of oil cake, and a deck load of horses, cows, and hay, weighing about 40 tons, and when last seen would have had about 76 tons of bunker coal. Passed within 300 yards of the "Acacia" in the Bay of Biscay during a hurricane. Shortly afterwards a violent squall struck the two ships, and the "Troubadour" was lost sight of. On its clearing away the "Troubadour" was nowhere to be seen.
London . .	Not known .	1885 *a.* 25 Jan. . *b.* ...	24	...	24	...	Not heard of after sailing. Laden with 1,269 tons of grain, 513 tons of general provisions, and 322 tons of bunker coal. Wreck Commissioner ruled that the loss was probably due to collision with icebergs, many of which were floating about at that time in the North Atlantic.
(1 Steamer).		1882.					
London .	North Sea .	29 Oct. . . 11 Nov.	14	...	...	...	No inquiry held. Laden with 800 tons of cargo.
(47 Steamers.)							
Savona . .	N. Atlantic .	1881. *a.* 2 April . *b.* 4 April	21	...	2	...	No inquiry held. Carried 1,150 tons of coal.
Cronstadt .	North Sea .	*a.* 8 Oct. . *b.* 10 Oct.	14	...	...	...	Statements of draught of water on sailing are unreliable, owing to the discrepancies between them. A leak was discovered at sea which the master neglected to attend to. Ship got into bad weather, made large quantity of water and fires were washed out. Pumps became choked with small pieces of coal.
Niewediep .	North Sea .	*a.* 11 Oct. . *b.* 15 Oct.	15	...	...	...	No inquiry held. Laden with 650 tons of coal.
Constantinople	Not known .	*a.* 7 March *b.* ...	21	...	21	...	Not heard of after sailing. No inquiry held. Laden with 1,524 tons of coal.
Shanghai .	Not known .	*a.* 25 Sept. *b.* ...	29	...	29	...	Not heard of after sailing. No inquiry held. Weight of cargo unknown.
Hong Kong .	Not known .	*a.* 29 Sept. *b.* ...	27	19	27	19	Not heard of after sailing. No inquiry held. Weight of cargo unknown.
Hamburg .	Not known .	*a.* 12 Oct. . *b.* ...	15	...	15	...	Not heard of after sailing. No inquiry held. Laden with 769 tons of coal.
Cronstadt .	Not known .	*a.* 13 Oct. . *b.* ...	18	...	18	..	Not heard of after sailing. No inquiry held. Laden with 1,036 tons of coal.
London . .	Not known .	*a.* 13 Oct. . *b.* 14 Oct.	17	...	17	...	Not heard of after being seen near Dudgeon Lightship on 14th October. No inquiry held. Laden with 1,025 tons of coal.
Valencia . .	Not known .	*a.* 24 Nov. *b.* 26 Nov.	17	...	17	...	Not heard of after being seen off Lowestoft on 26th November. No inquiry held. Laden with 900 tons cargo and 172 tons in bunkers.
Algiers . .	N. Atlantic .	1882. *a.* 3 Jan. . *b.* 6 Jan.	15	...	...	...	Vessel sprung a leak at sea, the source of which could not be discovered. It increased till it could no longer be kept under by the pumps, which frequently became choked with coal dirt. She was settling down and had lost steerage way when abandoned.

APPENDIX

TABLE

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins	Ft. Ins.	Ft. Ins.	
"Loch Awe" . 90 H.P.	4	210·5	28·8	15·5	16 6	7	853	671	1 9	2 4	15 3	Burntisland .
"Pelton" 98 H.P.	6	212·9	29·2	16·4	17 2	8	816	761	2 3	2 8 to 2 9	15 8	Newport, Mon.
"River Forth" . 120 H.P.	1	230·2	31·7	12·2	17 6	8	1,127	889	1 8	...	15 6½	Penarth .
"St. George" . 90 H.P.	1	190·5	28·9	13·0	13 0	7½	548	503	1 7	1 6 to 1 9	12 6	Swansea .
Missing—1882. . "Cleveland" . . 80 H.P.	3	170·0	25·2	17·9	18 9	7½	538	529	3 4	...	...	Grimsby .
"North Eastern" . 99 H.P.	11	219·2	30·4	16·9	17 10	7	1,070	842	2 0	2 5	...	Granton .
"Cyenus" 170 H.P.	4	264·6	34·7	23·1	24 4	9½	1,657	1,584	4 6	About 5 0	...	Cardiff .
Foundered—1883. "William Dickinson" 240 H.P.	5	30·0	35·0	24·3	25 8	10	2,111	1,976	4 9	...	...	Newcastle .

D—*continued.*

II.—*continued.*

Voyage. To	Where lost.	*a.* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Aarhaus . .	North Sea .	*a.* 5 Jan. . *b.* 7 Jan.	16	...	..	...	Ruled overladen by Inquiry Court at Dundee. Shipped sea over stern, which carried away cabin skylight, quarter-boat, and after steering gear, and filled and gutted the cabin. Shortly after another sea broke over forward, filling the well, smashing front of wheelhouse, crushing the port lifeboat and carrying away a ventilator to main hold flush with the deck. From that time the vessel had a heavy list to starboard. Hole in deck could not be effectually plugged, the steering gear got carried away, water gained upon the pumps, fires were put out, and vessel was finally abandoned.
Havre . .	Bristol Channel	*a.* 25 March *b.* 26 March	17	..	16	...	Wreck Commissioner ruled her unstable. About 25 tons of bunker coal was placed on bridge deck. Vessel took sudden list to port while steaming easy head to wind, could not be righted, was abandoned by some of the crew, and was seen by them to take a sudden heel and go down about two or three hours after time of first list.
Savona . .	N. Atlantic .	*a.* 18 Nov. *b.* 24 Nov.	19	...	...	...	Vessel ruled overladen. Steering gear broke down, water got below through ventilator being carried away by sea that broke upon well deck; but the hole was afterwards stopped. Pumps got command of water in hold, jury rudder was prepared, cargo jettisoned and weather moderated, when the vessel was abandoned. Ruled to have been prematurely abandoned. Laden with 1,497 tons of coal.
Nantes . .	Off Cornwall .	*a.* 28 Nov. *b.* 29 Nov.	18	1	10	1	Vessel ruled by Wreck Commissioner to have been too deeply laden and too much by the stern, so that water which came on deck washed the tarpaulins off the after hatchway, passed into the hold and caused the vessel to sink. Laden with 525 tons of coal, 100 tons of copper, and 60 tons of bunker coal.
Aarhaus . .	Not known .	*a.* 4 Jan. . *b.* ...	16	...	16	...	Not heard of after sailing. Laden with 548 tons of cargo and 59 tons in bunkers. No inquiry held.
Copenhagen .	Not known .	*a.* 6 Jan. . *b.* ...	19	1	19	1	Not heard of after sailing. This vessel had a long poop and top-gallant-forecastle. The pilot who took her down the Forth when she started upon the voyage said she was tender and easily heeled from the wind. The holds do not appear to have been completely filled. Wreck Commissioner ruled her unstable and said that the empty spaces in the hold should have been filled up from the coal in the 'tween decks. Coals liable to spontaneous combustion, but this was not likely to have been developed in course of voyage to Copenhagen
Suez .	Not known .	*a.* 25 Feb. *b.* ...	24	...	24	...	Not heard of after sailing. The Inquiry Court at Cardiff ruled that there was no evidence to enable an opinion to be formed respecting the cause of loss. The coal shipped was free from any tendency to spontaneous combustion. Laden with 1,696 tons of cargo and 694 tons of bunker coal.
Alexandria .	Mediterranean	1883. *a.* 9 Feb. . *b.* 27 Feb. .	26	...	...	...	The Inquiry Court at Valetta found that vessel became leaky in engine room compartment, after being repeatedly struck by heavy seas, but there was nothing to show the cause. The water gained upon the pumps, which were choked at first. The fires were put out, men all became exhausted, and the vessel was abandoned. Weight of cargo unknown.

APPENDIX

TABLE

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
Missing—1883.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Lord Cardigan" . 80 H.P.	28	170·4	26·8	15·0	15 6	6½	472	442	...	...	...	Newport .
"Mangerton" . 200 H.P.	4	285·0	35·3	24·5	25 10	10	2,005	1,903	4 10	4 10	...	Liverpool .
"St. Columba" . 300 H.P	2	321·0	35·8	24·0	25 6	11	2,223	2,082	4 8	...	...	Cardiff . .
"Copia" 130 H.P.	9	227·5	30·6	15·5	22 5	8	1,078	1,061	5 0	6 6½	17 0	Newcastle-on-Tyne .
"Fervent" 90 H.P.	7	214·0	29·4	16·0	16 9	8	901	739	...	About 2 0	...	Tyne . .
"H. D. Pochin" . 99 H.P.	12	216·2	31·2	16·5	17 5	8	1,011	811	2 0	About 2 3	16 6	W. Hartlepool
"Marie Stuart" . 120 H.P.	19	211·7	24·9	13·8	14 7	7½	565	485	2 9	2 8 to 2 11	...	Burntisland .
"Jubilee" . . 90 H.P.	16	196·5	29·2	16·6	17 6	8	790	669	2 5	2 11	15 7½	Hartlepool .
"Nebo" 180 H.P.	6	280·6	33·8	24·8	25 10	10	1,908	1,732	4 6	4 8½ to 5 0	...	Sunderland .
"Fidra" 150 H.P.	2	238·6	33·2	17·9	18 11	8½	1,139	1,020	2 4½	...	...	Newcastle, N.S.W. .
"Cherubini" . . 180 H.P.	3	261·3	36·2	21·3	22 8	9	1,776	1,517	3 0	3 9 to 4 0	...	Sunderland .
"Zelini" 90 H.P.	12	205·0	26·2	16.2	17 0	6½	671	586	2 4	...	...	Cardiff . .
"Said" 120 H.P. .	13	226·8	30·2	17·1	18 2	7	1,035	816	2 3	2 7½	...	Tyne . .

D.—*continued.*

II.—*continued.*

Voyage. To	Where lost.	*a.* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
		1883.					
Waterford .	Not known .	*a.* 28 Jan. . *b.* ...	12	...	12	...	Not heard of after leaving Newport. The Inquiry Court at Cardiff ruled that considering the quality of the coal the loss was not likely to be due to an explosion of gas, nor to spontaneous combustion, but that the age and depth of loading of the vessel makes it probable that she foundered in a heavy gale that was known to prevail shortly after she left Newport. Laden with 543 tons of coal.
Havannah .	Not known .	*a.* 27 Jan. *b.* 28 Jan.	26	...	26	...	Not heard of after leaving Holyhead. The Wreck Commissioner ruled that this vessel was too deeply laden.
Bombay .	Not known .	*a.* 28 Jan. . *b.* ...	34	...	34	...	Not heard of after sailing. Vessel was loaded with 2,128 tons of cargo, and 718 tons of bunker coal. The coal was "Ocean Merthyr." It gives off explosive gas freely, but is not liable to spontaneous combustion. It was shipped wet within 24 hours of being wrought. The Inquiry Court at Cardiff ruled that no opinion could be formed as to the cause of loss.
Messina .	Not known .	*a.* 25 Jan. *b.* 31 Jan.	22	...	22	...	Not heard of after passing St. Catharine's Point on 31st January. The Wreck Commissioner could not find anything to show cause of loss.
London . .	Not known .	*a.* 5 March. *b.* ...	17	...	17	...	Not heard of after sailing. Wreck Commissioner ruled her to be fully though not overladen, and thought she probably foundered in a heavy gale the day after she left port.
Wismar . .	Not known .	*a.* 5 March *b.* ...	18	...	18	...	Not heard of after sailing. Wreck Commissioner ruled that vessel was not in her usual trim and was too much by the head, and thought she must have foundered the day after she left port in the gale which probably proved fatal to the "Fervent."
Dunkirk .	Not known .	*a.* 5 March *b.* ...	18	...	18	...	Not heard of after sailing. Probably foundered in the gale mentioned in connection with the two preceding vessels. Wreck Commissioner could find nothing to show cause of loss.
Rochester .	Not known .	*a.* 5 March *b.* 6 March	16	...	16	...	Not heard of after being seen off Flamborough Head on 6th March. Wreck Commissioner ruled her fully though not overladen. Probably foundered in before-mentioned gale.
Bombay . .	Not known .	*a.* 3 April *b.* 3 April	26	...	26	...	Not heard of after being seen off the Newarp on 3rd April. She had a freeboard of 5 feet according to evidence of owner's manager and the pilot, and 4 feet 8½ inches according to evidence of master trimmer. The Wreck Commissioner found no evidence to show how the vessel was lost, or whether she was unstable or overladen.
Hongkong .	Not known .	*a.* 9 May . *b.* ...	About 32	...	Sup's'd 32	...	Not heard of after sailing. Laden with 1,250 tons of coal. No inquiry held.
Genoa . .	Not known .	*a.* 29 Aug. *b.* ...	24	...	24	...	Not heard of after sailing. Wreck Commissioner ruled that she was very deeply laden, but there was no evidence to show how she was lost.
Oporto . .	Not known .	*a.* 30 Aug. *b.* 30 Aug.	20	...	20	...	Not heard of after the pilot left her on 30th August. Wreck Commissioner ruled that there was no evidence to show to what cause her loss may be attributed. Laden with 761 tons of coal and 88 tons in bunkers.
London . .	Not known .	*a.* 11 Dec. . *b.* ...	18	. .	18	...	Not heard of after sailing. Wreck Commissioner ruled that there was nothing to show how she was lost, but said that the Court were disposed to consider that the freeboard was barely sufficient.

APPENDIX

TABLE

NAME.	Age.	Registered dimensions.			Moulded depth	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under upper-most deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Staffa" 90 H.P.	23	230·3	28·2	16·0	17 5	7	771	699	2 6	...	...	Shields . .
Foundered—1884. "Hornet" 98 H.P.	10	221·7	25·1	13·7	...	...	618	557	1 9	...	...	Newport .
"Llanarthen" . 160 H.P.	4	264·6	33·2	22·2	...	...	1,567	1,507	4 1½	...	20 6	Cardiff . .
"Linhope" . . 250 H.P.	6	300·0	36·3	25·2	26 8	...	2,319	2,144	5 0	...	...	Newcastle .
"Berwick" 65 H.P.	29	183·3	27·1	15·9	...	...	537	524	...	..	...	Sunderland .
"Miramar" 125 H.P.	4	230·2	31·2	20·8	...	...	1,190	1,124	...	...	...	Nagasaki .
Missing—1884. "Thames" 70 H.P.	25	181·5	23·4	11·9	...	...	395	372	1 9	...	...	Blyth . .
"Lightning" . 80 H.P.	29	205·0	27·2	19·3	...	...	698	676	...	...	...	Tyne . .
"Alliance" . . 99 H.P.	7	212·5	30·6	16·1	...	...	942	764	2 0	...	...	Cardiff . .
Foundered—1885. "Speke Hall" . 400 H.P.		361·4	37·0	26·2	...	...	2,672	2,502	6 8	...	...	Cardiff . .
"Seraglio" . . 175 H.P.	3	275·5	35·0	23·4	...	...	1,816	1,703	4 5	...	...	Cardiff . .
"Annie Vernon" . 70 H.P.	29	170·0	26·6	16·7	...	...	529	519	...	...	...	Cardiff . .
Missing—1885. "Alleghany . . 280 H.P.	4	300·3	36	25·5	26 8	...	2,283	2,143	5 0	...	...	Cardiff . .
"Derwent . . 70 H.P.	1	158·0	25·3	12·4	12 8	...	417	352	...	...	...	W. Hartlepool
"Burswell . 200 H.P	7	270·0	35·0	24·5	...	...	1,861	1,740	4 4	...	...	Newcastle .

D—*continued.*

II.—*continued.*

Voyage. To	Where lost.	*a.* Date of sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Cadiz . .	Not known .	*a.* 11 Dec. . *b.* 11 Dec.	19	...	19	...	Not heard of after the pilot left her outside Tyne Bar on 11th December. This vessel had a poop aft that had been lengthened, and a portion of it was considered by Lloyd's Surveyors to be of such weak construction as not to justify their classing her at Lloyd's. She was 4 feet by the stern on leaving port. The Wreck Commissioner ruled that she was too deeply laden. Laden with 725 tons of coal and 172 tons in bunkers.
		1884.					
Marseilles .	Bristol Channel	*a.* 24 Jan. . *b.* 27 Jan.	18	...	17	...	Loss appeared to be due to some person on board having unintentionally opened the sea-cock of the pulsometer as well as the valve on pipe leading to tank, so that water flowed in and filled the vessel. Laden with 622 tons cargo and 130 tons in bunkers.
Colombo .	N. Atlantic .	*a.* 25 Jan. . *b.* 4 Feb.	23	...	...	...	Encountered very bad weather in Bay of Biscay. Shipped large quantities of water fore and aft and rolled heavily. Sprung a leak in engine room; water could not be kept under by pumps, and vessel had to be abandoned.
Port Said .	Off Cape Finisterre . .	*a.* 29 May . *b.* 2 June	24	...	3	...	Laden with 2,543 tons cargo coal and 617 tons in bunkers. Took slight list to port during a fresh breeze, and while efforts were being made to trim her upright she suddenly took a very heavy list to port, putting her rail under water. Vessel continued to go over till she had to be abandoned.
Portsmouth .	Off Yorkshire	*a.* 14 Aug. . *b.* 14 Aug.	16	...	...	...	Laden with 732 tons of cargo and bunker coals. Inquiry Court at Sunderland ruled that there was nothing to show the cause of loss.
Hongkong .	China Sea .	*a.* 8 Sept. . *b.* 23 Sept.	26	...	24	...	No inquiry held. Weight of cargo not known.
Drontheim .	Not known .	*a.* 10 Oct. . *b.* 23 Oct.	13	...	13	...	Not heard of after leaving Invergordon on 23rd October. Ruled by Wreck Commissioner to have been overladen and undermanned, and unfit in general condition for such a voyage. Laden with 484 tons cargo and 64 tons in bunkers.
Drontheim .	Not known .	*a.* 23 Oct. . *b.* ...	16	...	16	...	Not heard of after sailing on 23rd October. Laden with 630 tons coal, 18 tons cement, and 60 tons soda. Inquiry Court unable to account for loss.
St. Nazaire .	Not known .	*a.* 3 Dec. . *b.* ...	16	...	16	...	Not heard of after sailing 3rd December. Laden with 1,120 tons cargo and 48 tons in bunkers. Inquiry Court unable to account for loss.
		1885.					
Bombay . .	Arabian Sea .	*a.* 12 May . *b.* 3 June	59	...	58	...	No inquiry held. Laden with 3,013 tons of cargo and bunker coal.
Bombay .	350 miles W. of Bombay.	*a.* 10 May . *b.* 13 June	25	...	...	...	Ship laboured and strained considerably in very heavy gale, shipped much water and sprung a leak in engine room; water could not be kept under and vessel had to be abandoned. Vessel was laden with 2,000 tons coal, 270 tons acids, dynamite, &c., and 380 tons bunker coal.
Plymouth .	Off Cornwall.	*a.* 18 Nov. . *b.* 19 Nov.	11	...	...	...	Sprung a bad leak in stokehold, the source of which could not be discovered. Water rose rapidly in the vessel and she had to be abandoned. Laden with 645 tons cargo and 38 tons in bunkers.
Galle . .	Not known .	*a.* 9 Jan. . *b.* ...	29	...	29	...	Not heard of after sailing. Laden with 2,708 tons cargo and 479 tons in bunkers. No inquiry held.
Chatham .	Not known .	*a.* 23 Oct. . *b.* ...	12	...	12	..	Not heard of after sailing. Laden with 417 tons cargo coal and 36 tons in bunkers. Wreck Commissioner ruled that there was nothing to show cause of loss.
Genoa . .	Not known .	*a.* 3 Dec. . *b.* 6 Dec.	26	...	26	...	Not heard of after passing Dover. She was laden with 2,118 tons of coal and 605 tons in bunkers. The Wreck Commissioner ruled that there was no evidence to show how she was lost.

APPENDIX

TABLE

Steamships laden with Metals

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Foundered—1882. "Athlete" 80 H.P.	27	159·5	23·4	13·9	14 11	6	363	341	2 0	2 3	..	Bilbao . .
"Regent" 200 H.P.	1	280·5	37·0	28·0	29 10	10	2,350	2,282	5 3	6 3½	24 0 (In dock.)	Cardiff . .
Missing—1882. "Vanguard" . . 95 H.P.	10	222·7	30·0	16·1	16 10	8	905	821	2 6	About 3 0	...	Huelva . .
Missing—1883. "Campanil" . . 70 H.P.	11	190·0	27·6	14·5	15 3	7½	660	550	2 0	...	...	Bilbao . .
"Asia" 90 H.P. .	11	210·7	25·1	15·5	16 4	7½	662	563	2 4	2 0¾	15 4	Middlesbro' .
"Dartmouth" . 61 H.P.	New.	155·0	25·1	10·9	11 6	7	367	290	...	...	10 4½	Duddon .
Missing—1884. "Elephant" . . 45 H.P.	11	133·8	23·3	12·0	12 7	...	356	294	...	...	...	London.
Foundered—1885. "Matador" . . 85 H.P.	2	191·0	27·1	13·7	14 8	8½	664	524	1 3	...	...	Santander
"Lucretia" . . 150 H.P.	7	260·5	33·3	21·8	23 3	...	1,515	1,436	4 0½	...	18 7	Gothenburg .
Missing—1885. "Magneta" . . 200 H.P.	1	237·4	32·1	16·5	17 7	9	922	787	2 9½	...	...	London. .

D—*continued.*

III.

AND METALLIC ORES.—(10 Steamers.)

Voyage. To	Where lost.	*a.* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Swansea . .	English Chan.	1882 14 May . 20 May	12	...	...	...	Ruled by Wreck Commissioner to be too deeply laden with 410 tons iron ore and 33 tons coal in bunkers. Laboured and strained very heavily in a high cross sea, and shipped large quantities of water; boiler primed badly, so that steam pressure had to be reduced. The coals were all burnt out, and vessel was drifting helplessly before the wind with 3 ft. 6 ins. to 5 ft. of water in the holds, when she was abandoned.
New Orleans .	N. Atlantic .	*a.* 6 Dec . *b.* 13 Dec.	28	...	...	...	This vessel was loaded with 2,412 tons of steel rails and 812 tons coal. Met with a hurricane soon after sailing. A tremendous sea struck the ship and carried away both rudder and rudder post. Vessel went over to starboard, gunwale under water, and lay helpless and unmanageable. It was found that the rails had shifted in all the holds, and as the vessel was making water freely from injuries at the stern, and nothing effectual could be done to trim the cargo, she was abandoned.
Newcastle-on Tyne . .	Unknown .	*a.* 24 Jan. . *b.* 26 Feb.	22	1	22	1	Not heard of after leaving Lisbon on 26th February. She was laden with 993 tons of copper pyrites, 115 tons of cork, and 80 tons bunker coal. Wreck Commissioner ruled that there was no evidence to show how she was lost.
Cardiff . .	Unknown .	1883 *a.* 31 Jan. . *b.* 31 Jan. .	15	...	15	...	Not heard of after being seen near Santander, on 31st Jan. Laden with 775 tons of iron ore, and 40 to 50 tons bunker coal. Inquiry Court at Cardiff were unable to come to any conclusion as to cause of loss.
Liverpool .	Unknown .	*a.* 5 March *b.* ...	15	...	15	...	Not heard of after sailing. Vessel was laden with 760 tons of pig iron, and about 73 tons bunker coal. The Inquiry Court at Middlesbro' ruled that she had not sufficient freeboard.
Newport, Mon.	Unknown .	*a.* 3 Dec. . *b.* ...	12	...	12	...	Not heard of after sailing. She was laden with 404 tons of iron ore and about 15 to 20 tons of bunker coal. The Inquiry Court at Liverpool were unable to account for her loss.
Portsmouth .	Unknown .	1884 *a.* 14 Feb. . *b.* 20 Feb.	12	...	12	...	Laden with heavy boilers on deck imperfectly secured, and had main hatchway uncovered.
Glasgow . .	Off Land's End	1885 *a.* 11 Jan. . *b.* 11 Jan. .	15	1	13	1	Laden with 650 tons iron ore and 70 tons bunker coal, Ventilator just forward of bridge house was carried away by fore-boom getting adrift in a gale. Hole in deck could not be stopped, the seas shipped washing the men away. Water found its way below in large quantities. Vessel settled fast down and was abandoned.
Civita Vecchia	North Sea .	*a.* 25 Nov. *b.* 28 Nov.	23	...	...	...	Laden with 1,700 tons of old rails. Struck by heavy seas and cargo shifted. Vessel lay over with lee rail in water and became unmanageable. Water gained upon pumps and vessel at last foundered.
Singapore .	Unknown .	*a.* 8 March *b.* 9 March	45	9	45	9	Not heard of after passing Prawle Point. Laden with a total dead weight of about 708 tons. Nothing to show how she was lost.

APPENDIX

TABLE

STEAMSHIPS LADEN

TABLE

STEAMSHIPS LADEN WITH OTHER THAN GRAIN,

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
Foundered—1881.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Ayton," 150 H.P.	5	249·8	33·5	23·5	24 7	9½	1,508	1,480	4 1	...	...	Sunderland .
Missing—1881. "Ardanmor". . 95 H.P.	5	201·7	28·0	15·6	16 3	7½	748	641	2 3	2 7½	14 6	Dunkirk .
Foundered—1882. "Iron Era" . . 80 H.P.	26	176·3	27·3	14·6	15 1	7	494	494	1 11	..	13 2½	Gothenburg .
Missing—1883. "Straits of Dover" 200 H.P.	9 mon.	285·0	38·2	27·4	28 8	10	2,352	2,326	6 0	...	...	Liverpool .
"Chavarri" . . 99 H.P.	12	216·0	31·2	16·6	17 3	8	1,022	823	1 10	...	...	Swansea .
"Alora," 99 H.P. .	10mon.	193·8	27·4	13·8	14 8	7½	729	536	1 3	...	...	Swansea .
Foundered—1884. "Glengarry". . 65 H.P.	17	161·6	24·0	13·7	...	...	409	378	...	...	...	Grangemouth
"Thomas Adams" . 90 H.P.	1	190·0	30·0	12·9	15 4	7½	807	594	1 6	...	14 6	Hamburg .
Missing—1884. "Uva," 99 H.P. .	New.	196·0	27·2	14·0	14 11	7	720	569	...	...	...	Liverpool .
Found red—1885. "Viceroy" 240 H.P.	15	318·8	37.6	27·7	28 11	...	2,401	2,381	6 4	...	...	New Orleans .
Missing—1885. "Cohanin" . . 150 H.P.	8	249·5	33·2	23·3	...	...	1,573	1,473	4 0	...	...	Coosaw . .

D.—*continued.*

IV.

WITH TIMBER. (Nil.)

V.

COAL, &c., CARGOES.—(11 Steamers.)

Voyage. To	Where lost.	*a.* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Hull . .	North Sea .	1881 *a.* 13 Oct. *b.* 16 Oct.	20	...	...	...	Laden with 1,800 tons of patent fuel. No inquiry held.
Greenock .	North Sea .	*a.* 23 Nov. *b.* 26 Nov.	17	...	17	...	Not heard of after passing the Longships on 26th Nov. Laden with about 896 tons of sugar in bags, and 52 tons bunker coal. Wreck Commissioner ruled that she was probably lost in the Bristol Channel during a violent gale, but that there was nothing to show whether she was driven on the rocks or foundered.
London . .	North Sea .	1882 *a.* 3 June . *b.* 6 June	14	...	...	...	Laden with timber, oats, and iron. Vessel appears to have suddenly sprung a leak whereby she became full of water forward. She gradually settled down forward and was abandoned about 135 miles from Tynemouth. Inquiry Court at North Shields ruled that the loss was due to some defect in the hull of the vessel. Weight of cargo, 633 tons.
Norfolk, Vir. .	Not known .	1883 *a.* 3 Jan. . *b.* ...	27	...	27	...	Not heard of after leaving Liverpool, 3 Jan. Laden with a total weight of about 1,000 tons, consisting of salt in bags and bulk, and guano in bags. Vessel also carried 400 tons of coal in bunkers for outward voyage, and 300 tons in one of her holds for homeward voyage. The Court found no evidence to account for loss.
Savona . .	Not known .	*a.* 27 Jan. . *b.* ...	20	...	20	...	Not heard of after sailing; no inquiry held. Laden with 1,620 tons patent fuel, 401 tons rails, and 258 tons of bunker coal.
Valencia . .	Not known .	*a.* 5 Feb. . *b.* ...	18	...	18	...	Not heard of after sailing. No inquiry held. Laden with about 630 tons patent fuel. Weight of bunker coal not known.
Rotterdam .	North Sea .	1884 *a.* 14 Feb. . *b.* 15 Feb.	12	...	2	...	Laden with 530 tons of chemical refuse and 45 tons bunker coal. Shipped heavy sea on port side. Weight of water threw her over and caused cargo to shift bodily to port; owing to soft and yielding nature of cargo, trimming was of no use, and was discontinued. The list gradually increased and vessel went down a few minutes after she was abandoned.
Greenock .	North Sea .	*a.* 18 Mar. . *b.* 21 Mar.	16	...	4	...	Laden with sugar in bags, 905 tons; weight of bunker coals unknown. Sprang a leak somewhere in the engine room during a gale of wind, the source of which could not be discovered, water gained on the pumps and put out fires, and vessel had to be abandoned.
Barcelona .	Not known .	*a.* 17 Dec. . *b.* 18 Dec.	15	...	15	...	Not heard of after passing Point Lynas, 18 Dec., laden with 400 tons pitch, 266 tons coal, & 112 tons in bunkers.
Bremen . .	North Atlantic	1885. *a.* 9 Dec. . *b.* 30 Dec.	27	1 stowaway	...	...	Laden with 1,280 tons of cotton and 260 tons of maize.
Hamburg .	Not known .	*a.* 14 April *b.* 17 April	25	...	25	...	Not heard of after leaving Norfolk, Va., 17 April, laden with 1,907 tons phosphate rock, and 282 tons bunker coal. Wreck Commissioner could find nothing to account for loss, and thought it might have been caused by collision with ice.

APPENDIX

TABLE

STEAMSHIPS LADEN WITH

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross	Under uppermost deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Foundered—1881. "Clan Macduff" . 200 H.P.	11	326·1	36·1	27·7	29 3	11	2,328	2,312	6 0	About 7 0	...	Liverpool .
"Bath City" . . 180 H.P.	1	260·0	34·5	22·5	23 9	9½	1,724	1,597	3 10	4 10 to 4 11	20 0	Bristol .
Missing—1881. "City of London." . 300 H.P.	18	374·0	40.5	26·1	27 2	11	3,409	3,405	4 4	...	24 4½	London .
Foundered—1882. "Bendigo" . . 150 H.P.	5	250·0	32.0	20 0	21 4	9	1,414	1,159	2 0	2 5	...	Liverpool
"Chiapas" . . 200 H.P.	New.	275·0	33.2	19·9	21 1	9½	1,582	1,406	3 8	4 2½ to 4 4	...	Glasgow
Missing—1882. "Ballina," 121 H.P.	4	170·5	23·2	11·4	12 1	6	341	287	1 0	10½ins	...	Liverpool .
"City of Limerick" 250 H.P.	27	331·1	34·4	30·4	31 9	11	2,536	2,505	2 0	...	...	New York .
"Titania," 165 H.P.	2	270·1	35·2	24·5	25 10	10	1,961	1,787	4 9	5 8½	...	New York .
"Virago," 250 H.P.	11	282·0	34·8	19·0	20 9	9½	1,809	1,492	2 7	3 4	18 3½	Hull . .
Foundered—1883. "Kenmure Castle" 200 H.P.	10	286·0	35·2	24·9	26 5	10	1,951	1,847	5 1	About 6 7	...	London .

D.—*continued.*

VI.

General Cargoes—(16 Steamers.)

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board		Lives lost.		REMARKS
			Crew.	Passengers.	Crew.	Passengers.	
		1881					
Bombay .	Bristol Channel	a. 18 Oct. . b. 21 Oct.	42	19	19	12	Laden with 1,382 tons general merchandise, 808 tons cargo coal, and 818 tons bunker coal. Wreck Commissioner ruled loss was due to water having got into engine room, at first through fiddley gratings, and afterwards through a rent in the port side of fiddley house, and to the pumps being choked so that the water rose until the fires were put out.
New York .	N. Atlantic .	a. 10 Nov. b. 3 Dec.	26 &	1 stowaway	10 &	1 stowaway	Laden with 1,544 tons general cargo, and 550 tons bunker coal. From 17 Nov. till 3 Dec., when the vessel foundered, she was battling with a succession of gales, such as, according to the Wreck Commissioner, has seldom or never been encountered even in the Atlantic. The rudder-head gave way and there was a bad leak at the stern, the vessel became unmanageable, and she filled and went down.
New York .	Not known .	a. 13 Nov. b. 14 Nov.	41	...	41	...	Not heard of after being seen off the Lizard, 14 Nov. Laden with 2,150 tons of cargo, consisting chiefly of cement and dried fruit, steel blooms, rags, wool, &c. She had also 1,010 tons of coal on board. A shade deck was fitted to this vessel in 1879, and the deck houses, which formerly ran fore and aft were removed. The Wreck Inquiry, held at Liverpool, considered that she was fully but not over laden, and there was no evidence to point to the probable cause of loss.
		1882.					
Demerara .	Off Co. Cork .	a. 29 Sept. b. 1 Oct.	25	1	1	1	Laden with 1,255 tons general cargo, and 588 tons bunker coal. The Wreck Commissioner attributed the loss to overloading and to the water which came on deck, not being able to get away owing to the jamming of ports on starboard side.
Demerara .	Off Cork Harb.	a. 28 Dec.. b. 30 Dec.	35	4	1	...	The Wreck Commissioner ruled that the loss was due to water getting into the fore-hold, probably through a leak, for which there was nothing to show cause.
Ballina . .	Not known .	a. 5 Jan. . b. ...	15	...	15	...	Not heard of after leaving Liverpool on 5 Jan.
London . .	Not known .	a. 8 Jan. . b. ...	35	8 cattlemen	35	8 cattlemen	Not heard of after sailing. Weight of cargo unknown.
N'castle-on-Tyne	Not known .	a. 22 Jan. . b. 25 Jan.	27	...	27	...	Not heard of after being spoken one day's sail from New York on 25 Jan. Laden with about 2,100 tons provisions, and 400 to 440 tons bunker coal. Wreck Commissioner ruled that there was no evidence to show how she was lost.
Odessa . .	Not known .	a. 31 May. b. 1 June	32	1	32	1	Not heard of after passing Dover on 1 June. Laden with 1,059 tons general cargo, 752 tons cargo coal, and 506 tons bunker coal. The Inquiry Court at Hull ruled that she was very heavily laden, but that there was no evidence to show how she was lost.
		1883.					
Shanghai . .	Bay of Biscay	a. 23 Jan. . b. 2 Feb.	38	8	28	...	This was a flush deck vessel without forecastle or poop; and the loss appears to have been due to a door in the after-part of the saloon deck-house having been stove in, and to the water thus passing down a scuttle into the lazarette, and from thence into the afterhold.

APPENDIX

TABLE

Name.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Glamorgan" . 400 H.P.	10	320·1	36·6	28·8	29 10	11	2,568	2,397	4 2	9 4	21 5	Liverpool .
"Navarre" . . 120 H.P.	17	230·2	30·2	15·5	16 6	7½	855	685	2 9½	4 2	12 10	Copenhagen .
Missing—1883. "City of Glasgow" 98 H.P.	7	204·7	27·5	15·7	16 4	7	666	582	1 9	...	...	Glasgow .
Foundered—1884. "Pochard" . . 250 H.P.	1	260·2	33·1	15·4	18 2	10½	1,135	1,006	...	...	16 6	Liverpool
Foundered—1885. "Vale of Calder" . 98 H.P.	27	221·4	27·2	15·6	...	...	759	635	...	...	15 10	Liverpool .
Missing—1885. "Humber" . . 350 H.P.	5	330·0	35·8	25·6	...	...	2,371	2,200	...	6 0 to 6 6	...	Yew York .

TABLE

STEAMSHIPS IN BAL-

Foundered—1884. "Schelde and Rhyn" 65 H.P.	11	210·9	27·5	8·3	...	...	470	441	1 6	...	4 9	Antwerp .
Missing—1884. "Coniston" . . 250 H.P.	4	300·0	36·4	25·2	...	...	2258	2,154	5 0	...	...	Liverpool .

TABLE

STEAMSHIPS. CARGOES

D—*continued.*

VI.—*continued.*

Voyage. To	Where lost.	*a.* Date of Sailing. *b* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Boston, Mass. .	N. Atlantic .	*a.* 8 Feb. . *b.* 16 Feb.	51	67	76	...	Laden with 1,416 tons of general cargo, and 743 tons bunker coal. The Wreck Commissioner ruled that the loss was due to extraordinary violence of the sea, which swept the vessel's deck.
Leith . .	North Sea .	*a.* 2 March *b.* 7 March	20	67	16	56	Laden with general cargo and cattle. Heavy sea broke over her, damaging deck and deck fittings. From that time vessel had a list to port. Pumps were not able to clear water out of engine room. The list continued to increase, and was increasing rapidly just before she foundered. Wreck Commissioner ruled that the loss was probably due to springing a leak during an exceptionally heavy gale.
Oporto . .	Not known .	*a.* 29 Aug . *b.* ...	23	...	23	...	Not heard of after sailing. Vessel carried 515 tons cargo and 130 tons of bunker coal. No inquiry held.
Rotterdam .	Off Holyhead	1884. *a.* 6 Dec. . *b.* 7 Dec.	23	...	23	...	Fully laden with rock salt, ground nuts, &c. After passing the South Stack, was seen to turn round and go back towards Liverpool, but made no signal that anything was wrong. There was a very heavy sea, and vessel rolled considerably. Was afterwards seen with a bad list to port and rolling heavily. When rounding the North Stack she was observed from the shore to be going very slowly, and suddenly a body of smoke or steam was seen, the bow of the vessel rose up and she went down stern foremost.
Limerick .	Irish Sea .	1885. 22 Feb. . *b.* 22 Feb.	17 &	4 stowaways	...	...	Laden with 603 tons of coal, including bunker coal, and 280 tons of general cargo, of which 40 tons was stowed on deck. Heavy seas broke on board. Deck cargo appears to have floated about and injured engine and boiler casings, so that water found its way into engine room. Fires were washed out and vessel was gradually sinking, and had to be abandoned. Was afterwards seen to go down head foremost.
London . .	Not known .	*a.* 15 Feb . *b.* ...	56	...	56	...	Not heard of after sailing. Laden with general cargo. Inquiry Court ruled that loss was probably due to her having foundered in a gale that sprung up soon after she sailed, or to her becoming imbedded in ice in the North Atlantic.
VII.							
EAST (2 Steamers).							
Buenos Ayres .	Atlantic .	1884. *a.* 7 June . *b.* 8 Nov.	15	...	1	...	Laboured and strained heavily while crossing Bay of Biscay. Was surveyed and repaired at Bahia, and left for River Plate. A breeze sprang up, she again strained considerably, and made so much water that she was abandoned. Soon afterwards she broke in two and went down.
New York .	Not known .	*a.* 24 Dec. . *b.* ...	27	...	27	...	Laden with about 705 tons of coal, 150 tons stone ballast, and about 350 tons water ballast. Not heard of after sailing. Inquiry Court ruled that there was no evidence to show cause of loss.
VIII.							
UNKNOWN. (Nil.)							

APPENDIX

DETAILED LIST OF IRON SAILING SHIPS BELONGING TO THE UNITED KINGDOM OF AND ABOVE 300 TONS GROSS REGISTER, 1881, 1882, 1883,

TABLE I.—IRON SAILING SHIPS LADEN

Name.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
												(*a.*) WHEAT
Missing—1881.	Years.	ft.	ft.	ft.	ft. ins.	ins.			ft. ins.	ft. ins.	ft. ins.	
"Eurynome" .	19	240·9	35·9	22·6	24 1	8½	1,404	1,267	4 0	...	20 6	Geelong .
"St. Mirren" .	5	229·4	37·1	22·8	24 2	9	1,426	1,297	4 1	...	...	Calcutta .
"Archibald Fuller"	13	182·6	30·8	18·8	19 11	7	718	689	3 7	...	...	San Francisco
"Eblana" . .	17	211·4	36·2	24·4	25 9	9	1,351	1,285	4 6	...	...	Calcutta .
Missing—1882. "Devock Water" .	1	216·0	34·4	20·3	21 8	8½	1,056	995	3 9	...	...	San Francisco
Foundered—1883. "Jessica" . .	20	165·8	28·0	17·5	18 6	7	546	523	2 11	3 1½	15 10	Chili . .
Missing—1883. "Beatrice" . .	18	172·2	27·8	17·7	18 11	7	591	576	3 0	...	...	Llico . .
"Loch Dee" . .	13	187·6	30·1	18·6	19 6	7½	726	691	3 10	...	...	Lyttleton, N.Z.
"Loch Fyne" .	7	228·5	36·0	21·3	22 8	9	1,270	1,114	4 1	...	...	Lyttleton, N.Z.
"Aberaman" .	8	206·5	35·1	21·8	23 2	8½	1,126	1,062	4 7	4 7	19 8½	San Francisco
"Roxburgshire" .	7	203·9	32·6	19·8	21 2	8	988	905	3 7	...	...	Astoria, Ore. .
Foundered—1885. "Kirkwood" . .	16	221·0	35·2	23·0	...	...	1,324	1,188	4 9½	...	...	Portland, Ore.
Missing—1885. "Yarra Yarra" .	8	231·2	35·8	20·9	21 9	...	1,290	1,154	3 10½	...	...	Astoria, Ore. .

E.

WHICH HAVE BEEN REPORTED TO THE BOARD OF TRADE AS FOUNDERED AND MISSING, DURING THE FIVE CALENDAR YEARS, 1884 AND 1885.

WITH GRAIN CARGOES.—(17 Vessels.)

Voyage To	Where lost.	a Date of Sailing. b Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS
(13 Vessels.)							
Havre	Not known	1881. a. 19 May. b. ...	26	...	26	...	Not heard of after sailing, 19 May. Court found she was too deeply laden by five or six inches, but no evidence to show how she was lost. Laden with 1,933 tons of wheat.
Liverpool	Not known	a. 8 July. b. ...	28	...	28	...	Not heard of after sailing, 8 July. No inquiry held. Laden with wheat, linseed, castor oil and jute; in all 1,955 tons.
Queenstown	Not known	a. 22 Aug. b. 4 Sept.	17	...	17	...	Not heard of after being spoken at sea, 4 September. Court found that vessel sailed overladen to the extent of three or four inches, but otherwise in good condition. Laden with 1,052 tons wheat and 12 tons of lumber.
Liverpool	Not known	a. 4 Aug. b. 10 Oct.	25	...	25	...	Not heard of after being spoken off St. Helena, on 10 October. No inquiry held. Laden with 1,752 tons of cargo.
Cape Town	Not known	1882. a. 2 Sept. b. 2 Oct.	22	...	22	...	Not heard of after being spoken at sea, on 2 October. No inquiry held. Weight of cargo 1,550 tons.
Cork	S. Pacific	1883. a. 13 Feb. b. 7 March	15	...	...	...	Court considered that loss was entirely due to a hurricane which threw vessel on her beam ends and caused cargo to shift. The sea, with the wreckage, knocked battens from main and after hatches, and a great quantity of water got down among the grain, which ultimately choked the pumps. Weight of cargo 546 tons.
United Kingdom	Not known	a. 7 Feb. b. ...	15	...	15	...	Not heard of after sailing. Carried about 900 tons cargo. No inquiry held.
United Kingdom	Not known	a. 3 March b. ...	17	...	17	...	Not heard of after sailing. Laden with 1,082 tons of wheat. No inquiry held.
Falmouth	Not known	a. 14 May. b. ...	32	4	32	4	Not heard of after sailing. Weight of cargo, 1,645 tons. The wheat was in bags, and was stowed up to the beams on the lower deck, keeping both ends of ship clear. The sacks in lower hold were stowed fore and aft, and in 'tween deck athwartships. Inquiry Court ruled that there was no evidence to account for loss.
Falmouth	Not known	a. 20 May. b. ...	20	...	20	...	Not heard of after sailing. Wreck Commissioner thought she was too deeply laden, especially as she had to round the Horn in winter.
United Kingdom	Not known	a. 7 Oct. b. ..	19	...	19	...	Not heard of after sailing. Carried 1,432 tons of wheat. No inquiry held.
Liverpool	N. Atlantic	1884. a. 2 Oct. 1885. b. 24 Feb.	26	...	..	...	Vessel met with very violent gale, was thrown on beam ends and partially dismasted. She was finally abandoned with 6 feet of water in the hold. Laden with 1,767 tons cargo.
Queenstown	Not known	a. 12 Feb. b. ...	25	2	25	2	Inquiry Court thought that a dismasted vessel seen drifting towards Beaver Island, one of the Falkland group, was most probably the "Yarra Yarra," and Court ruled that she was dismasted in a heavy gale in the vicinity of the Falkland Islands and drifted on the rocks. She was laden with 1,789 tons of wheat.

APPENDIX

TABLE

Name.	Age	Registered dimensions. Length.	Breadth.	Depth.	Moulded depth.	Depth of keel.	Tonnages. Gross.	Under upper-most deck.	Freeboard. By disc.	When last known.	Mean draught at sailing.	From
												(*f.*) Rice
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Missing—1881. "Firth of Cromarty"	1	202·4	32·5	19·0	20 5	8	957	865	3 7	About 4 0	18 6 in river.	Rangoon .
Missing—1884. "Cassiope" . .	9	253·0	40·0	23·6	...	...	1649	1,464	4 9	...	...	Rangoon .
Foundered—1885. "British Statesman"	18	217·0	36·0	22·8	...	...	1262	1,199	4 4	...	...	Calcutta. .
												(*k.*) Not Stated
Missing—1881. "Halton Castle" .	19	159·3	26·1	18·0	19 0	7	478	451	3 0	...	...	New York .

TABLE

Iron Sailing Ships laden with

Foundered—1881. "Globe" . .	14	177·8	28·0	19·2	20 5	7	736	684	3 6	...	17 9	Newcastle .
"Sarco" . .	5	202·6	31·9	19·6	20 10	8	861	822	3 6	...	...	North Shields
Missing—1881. "British Sovereign"	17	213·2	34·2	22·0	24 2	9	1,292	1,199	4 3	...	...	Dundee . .
Foundered—1882. "Fort George" .	27	171·5	30.2	20·4	21 9	7½	732	732	3 9	...	17 5½	Liverpool .
"Nelson" . .	20	214·4	36·2	22·9	24 3	9	1,333	1,176	4 4	...	...	South Shields.

E.—*continued.*

I.—*continued.*

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
(3 vessels).							
Falmouth .	Not known.	1881. a. 26 April. b. 27 June.	21	...	21	...	Not heard of after being spoken at sea on 27th June. Wreck Commissioner condemned practice of stowing rice cargoes in longers, and of ventilating them on the Heap's system as was done in this case.
Falmouth .	Not known.	1884. a. 23 Feb. . b. ...	30	...	30	...	Cargo stowed on the bag system of ventilation, which is liable to give way and cause shifting in bad weather. Nothing to show how she was lost. Laden with 2,110 tons of rice.
Demerara .	Bay of Bengal.	1885. a. 15 Aug. b. 17 Aug.	29	...	17	...	Cargo not secured at the ends of the hold. Tiers of bags merely stepped in a sloping direction at the ends leaving empty space. Vessel struck by heavy seas, and heeled over upon her beam ends. Captain and mate felt a heavy thud below as though cargo was shifting. A loud report was heard, when one of the dead lights blew out of the weather-side through the force of the compressed air in the vessel. She turned over and went down within three minutes of the time when first struck by the sea. She was laden with 1,724 tons of rice.
(1 vessel).							
Queenstown .	Not known.	1881. a. 13 April. b. 17 April.	10	...	10	...	Not heard of after leaving New York river, 17th April. No inquiry held. Weight of cargo about 750 tons.
II.							
Coal (23 vessels).							
Valparaiso .	S. Atlantic .	1881 a. 19 Mar. b. 30 May .	19	...	...	...	Laden with 1,078 tons of coal. The Court found that a heavy sea during a gale of wind threw the vessel on her beam ends, shifted her cargo, disabled her pumps, and caused her to make so much water that it could not be kept under. More than usual care had been taken by the provision of shifting boards, but these were not carried from deck to deck.
,, .	,, .	a. 19 June . b. 7 Sept. .	19	...	6	...	The Court found that a succession of heavy seas threw vessel on her beam ends, and shifted the whole of cargo. Two large spars lashed on deck then broke adrift, and by force of sea stove in the front of the poop, thereby causing vessel to make a great deal of water. Court could not say whether cargo was properly stowed, but shifting boards appeared to have been fitted. Laden with 1,215 tons of cargo and 15 tons of bunker coal.
San Francisco .	Not known .	a. 28 April. b. ...	23	...	23	...	Not heard of after sailing. No inquiry held. Weight of cargo 1,762 tons.
Valparaiso .	S. Atlantic	1882 a. 4 March. b. 29 Mar.	15	...	...	...	No inquiry held. Laden with 1,011 tons of coal.
,, .	North Sea .	a. 14 Oct. . b. 24 Oct. .	23	...	...	...	Laden with 1,738 tons coal. During very bad weather a sudden gust caused vessel's cargo to shift, and she took a heavy list, which afterwards increased, and necessitated her abandonment.

APPENDIX

TABLE

Name.	Age.	Registered dimensions. Length.	Breadth.	Depth.	Moulded depth.	Depth of keel.	Tonnages. Gross.	Under uppermost deck.	Freeboard. By disc.	When last known.	Mean draught at sailing.	From
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Missing—1882. "Min-y-don"	7	222·0	35·3	21·0	22 4	8½	1,149	1,032	4 2	...	...	Newcastle N.S.W.
"Khokand"	2	215·8	35·1	21·0	22 7	8½	1,153	1,055	4 0	...	...	Hull
"Largs"	6	183·4	32·1	18·0	19 2	8	772	708	3 4½	3 9½ to 3 10½	16 4	Newcastle-on-Tyne
"Wigton"	7	191·0	31·6	18·5	19 5	8	765	725	3 3½	See Remarks.	17 6½	Garston
"Ghazeepore"	14	236·4	38·0	23·7	25 2	9	1,557	1,418	4 11	See Remarks.	...	Shields
Foundered—1883. "Eller Bank"	7	232·4	35·2	21·1	22 4	8½	1,171	1,125	3 11	...	...	Hull
Missing—1883. "Darjeeling"	2	269·6	39·6	24·1	25 11	10	2,002	1,869	4 9	5 7½	22 0½	Cardiff
"Ardentinny"	13	151·7	28·0	13·7	14 5	7½	394	355	2 6	...	...	Glasgow
"West Ridge"	14	220·2	36·1	25·0	26 4	9	1,466	1,377	4 6	5 6	22 6½	Liverpool
"Lady Bird"	17	159·3	25·3	16·8	17 11	7	498	469	3 2	...	...	Shields
"Buckinghamshire"	15	238·3	37·5	23·1	25 3	9	1,533	1,368	4 10	...	...	Shields
Foundered—1884. "Moel Rhiwan"	6	221·0	35·1	21·3	22 11	...	1,117	1,056	3 7	...	19 6	Newport
"Aros Bay"	9	245·7	37·2	21·4	22 8	...	1,482	1,323	4 0	...	...	Dundee
Missing—1884. "Adelaide"	9	181·6	30·7	18·2	19 4	...	712	670	3 3	...	...	S. Shields
"Talca"	19	142·5	26·6	16·8	...	..	440	425	3 0	...	...	Swansea
"County of Aberdeen"	5	281·0	40·4	24·1	...	...	1,943	1,803	5 0	...	...	Cardiff
Missing—1885. "Blanche Maud"	11	180·0	29·5	17·8	...	...	656	612	3 2	...	...	Leith
"Noss Head"	1	220·2	3·46	20·0	21 10	8	1,104	1,023	4 4½	...	...	Sydney, N.S.W.

E.—*continued.*

II.—*continued.*

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Lyttleton, N.Z.	Not known	a. 10 Feb. b. ...	22	...	22	...	Not heard of after being seen at sea at end of Feb. No inquiry held. Laden with 1,567 tons of coal.
San Francisco	Not known	a. 20 Jan. b. 3 June	21	...	21	...	Not heard of after leaving Liverpool on 3rd June. She was laden with 1,260 tons of coal. The Court found no evidence as to cause of loss.
Valparaiso	Not known	a. 30 May. b. 11 June.	14	...	14	...	Not heard of after passing through the Downs on 11th June. Wreck Commissioner found nothing to show how vessel was lost.
,,	Not known	a. 6 June. b. ...	16	...	16	...	Not heard of after being seen off Madeira in June, 1882. Freeboard 3 ft. 9 in. to 3 ft. 10 ins. according to Board of Trade Surveyor, or 4 ft. 1 in. to 4 ft. 2 in according to owner. Wreck Commissioner thought vessel may have encountered a violent storm off Cape Horn, with which she, being so fully laden, could not successfully battle.
Calcutta	Not known	a. 14 Oct. b. ... 1883	34	...	34	...	Not heard of after sailing. Wreck Commissioner found nothing to show how vessel was lost. Laden with 2,184 tons of coal.
San Francisco	S. Pacific	a. 24 April. b. 1 Aug.	24	...	...	...	Laden with 1,500 tons coal. No inquiry held.
Calcutta	Not known	a. 19 April. b. 30 April.	35	...	35	...	Not heard of after being seen near Cape Finisterre, on 30th April. The Court found nothing to justify any conclusion as to how vessel was lost.
Buenos Ayres	Not known	a. 24 May. b. ...	11	...	11	...	Not heard of after leaving Greenock on 24th May. Carried 355 tons of cargo. The Court could form no opinion as to cause of loss.
Bombay	Not known	a. 28 June. b. 12 July.	28	...	28	...	Not heard of after being spoken at sea on 12th July. The Court found nothing to which vessel's loss could be attributed.
Iquique	Not known	a. 25 Aug. b. 1 Sept.	16	...	16	...	Not heard of after being seen off Beachy Head, on 1st Sept. Vessel was laden with 736 tons of cargo. The Wreck Commissioner found nothing to show how she was lost.
Rangoon	Not known	a. 2 Oct. b. 7 Nov. 1884.	28	...	28	...	Not heard of after being spoken at sea on 7th Nov. Laden with 1,940 tons cargo. No inquiry held.
Valparaiso	Bristol Channel	a. 2 Feb. b. 13 Feb.	20	...	...	...	Loss caused by cargo shifting over to port side and keeping vessel upon her beam ends with the lee rail under water, in which position she fast filled with water, and was abandoned. She was laden with 1,623 tons coal.
San Francisco	Atlantic	a. 4 April. b. 28 June.	26	...	..	...	Thrown upon her beam ends during a hurricane. Vessel partially dismasted, steering gear gave way, and she was quite unmanageable when abandoned. Laden with 2,048 tons coal.
Valparaiso	Not known	a. 4 May. b. 11 July.	18	...	18	...	Not heard of after being spoken on 11th July. Laden with 1,110 tons cargo. Inquiry Court could not arrive at any conclusion as to cause of loss.
Cape Town	Not known	a. 18 Nov. b. ...	12	...	12	...	Not heard of after sailing. Carried a cargo of 664 tons of coal. Court could not arrive at any conclusion as to cause of loss.
Bombay	Not known	a. 22 Dec. b. 28 Dec. 1885	30	...	30	...	Not heard of after being seen off the Western Islands on 28th Dec. Inquiry Court could not arrive at any conclusion as to cause of loss. Cargo consisted of 2,790 tons of coal.
Valparaiso	Not known	a. 25 Feb. b. 8 May	17	...	17	...	Laden with 997 tons coal. Not heard of after being spoken on 8th May. Inquiry Court could not arrive at any conclusion as to cause of loss.
Portland, Or	Not known	a. 30 Aug. b. ...	25	...	25	..	Not heard of after sailing. Laden with 1,549 tons coal. No inquiry held.

APPENDIX

TABLE

IRON SAILING SHIPS LADEN WITH METALS

Name.	Age.	Registered dimensions. Length.	Breadth.	Depth.	Moulded depth.	Depth of keel.	Tonnages. Gross.	Under uppermost deck.	Freeboard. By disc.	When last known.	Mean draught at sailing.	From
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Foundered—1881. "India" . .	20	187·0	32 0	21·5	22 7	8	912	839	4 6	...	...	Barrow-in-Furness .
Missing—1882. "Oweenee" . .	2	227·3	34·1	21·0	22 5	9	1,145	1,085	4 0	...	...	Londonderry .
"Cape Comorin" .	13	229·0	36·0	22·2	23 6	9	1,257	1,181	4 2	4 11	20 4½ at Glasgow	Glasgow .
Missing—1883. "Liverpool" . .	New	275·5	42·0	24·1	25 6	10	2,088	1,928	4 6	5 8	22 2 (in dock)	Greenock .
Missing—1884. "Pizarro" . .	8	233·0	36·3	22·8	...	...	1,439	1,302	4 5	...	...	Barrow .
"Sarah Scott" .	20	177·6	28·1	18·2	...	...	703	622	3 5	...	...	Middlesbrough .
Missing—1885. "Arctic" . .	10	176·0	30·1	17·4	19 0	...	637	593	3 2	...	...	Middlesbrough

TABLE

IRON SAILING SHIPS LADEN WITH OTHER THAN

Foundered—1881. "Battle Axe" .	7	181·2	30·0	17·9	18 7	7½	648	599	3 0	...	14 9½	Peru . .
"Thomas Blythe" .	22	135 0	25·0	17·0	17 8	6½	386	367	2 2	...	15 1½	Peru . .
Missing—1881. "Loch Maree" .	8	255 8	38·6	22·9	24 4	9½	1657	1438	4 4	...	...	Geelong .
Missing—1882. "Glencoe" . .	28	185·0	30·0	18·8	19 11	7	751	694	3 9	...	...	Pisagua .
Foundered—1883. "Durham" . .	17	198·6	34·3	20·3	21 8	8	998	895	4 0	...	19 2	Autofagasta .
Missing—1884. "Inverarnan" .	1	248·0	38·0	23·0	...	...	1531	1422	4 9	...	...	Java . .
"Grassendale" .	3	266·5	39·1	23·6	...	...	1842	1720	...	...	...	New York .

E.

III.

AND METALLIC ORES (7 Vessels).

Voyage. To	Where lost.	a. Date of Sailing. b. Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
Port Pirie, S.A.	S. Atlantic .	1880. a 15 Dec. . 1881. b. 24 Feb. .	19	...	...	...	Laden with 1,216 tons railway iron. Court found that she encountered heavy weather, became leaky, and had to be abandoned.
Baltimore .	Not known .	1882. a. 27 Feb. . b. ...	20	...	20	...	Not heard of after sailing. Laden with 1,015 tons of pig iron and 450 tons potatoes.
Buenos Ayres .	Not known .	a 29 Sept. . b. 30 Sept. 1883.	27	...	27	...	Not heard of after being spoken off Rathlin Island, on 30th Sept. Laden with iron bars and sleepers. Court found nothing to account for the loss.
Buenos Ayres .	Not known .	a. 13 Jan. . b. 21 Jan. .	38	...	38	...	Not heard of after being seen off Rathlin Island, on 21st Jan. Laden with iron, &c. Court found no evidence to show cause of loss.
Cooktown .	Not known .	a. 1 Dec. . 1884 b. 1 March	29	...	29	...	Not heard of after being seen on 1st March. Carried 2,000 tons cargo. No inquiry held.
Buenos Ayres .	Not known .	a. 15 Dec. . b. ... 1885	16 &	pilot	16 &	pilot	Not heard of after sailing. Laden with 1,000 tons of cargo. Court could not arrive at any conclusion as to cause of loss.
Buenos Ayres .	Not known .	a. 20 Oct. . b. 29 Oct. .	13	...	13	...	Not heard of after leaving the Downs on 29th Oct. No inquiry held. Weight of cargo unknown.

V.

GRAIN, COAL, &c., CARGOES (7 Vessels).

Liverpool .	S. Atlantic .	1881. a. 25 Feb. . b. 4 April .	17	...	...	...	Laden with 828 tons sugar, &c. No inquiry held.
Liverpool .	N. Atlantic .	a. 9 April . b. 6 August	12	...	...	...	Laden with sugar. No inquiry held. Weight of cargo unknown.
London . .	Not known .	a. 29 Oct. . b. 30 Oct. .	36	...	36	...	Not heard of after being seen off Kent's Group, S. Pacific, on 30th Oct. Laden with wool. No inquiry held. Laden with 1,370 tons of cargo and 453 tons of ballast.
United Kingdom	Not known .	1882. a. 21 Dec. . b. ...	16	...	16	...	Not heard of after sailing. Laden with 1,090 tons of nitrate of soda. No inquiry held.
Falmouth .	Off Cape Horn	a. 22 Nov. 1883. b. 3 Jan. .	21	...	...	...	Laden with 1,350 tons of nitrate. Abandoned off Cape Horn. Dismasted, and boats, pumps, &c., destroyed in a gale.
Queenstown .	Not known .	a. 24 Oct. 1884. b. 7 Jan. .	30	...	30	...	Not heard of after being spoken on 7th January. Laden with 2,080 tons of sugar. Inquiry abandoned. There was no evidence as to the trim and condition of the vessel at time of sailing.
Shanghai .	Not known .	a. 17 May b. ...	29	3	29	3	Not heard of after sailing. Laden with a cargo of 2,600 tons of Petroleum oil. Inquiry Court could not find anything to account for the loss.

APPENDIX

TABLE

IRON SAILING SHIPS, LADEN WITH

NAME.	Age.	Registered dimensions. Length.	Registered dimensions. Breadth.	Registered dimensions. Depth.	Moulded depth.	Depth of keel.	Tonnages. Gross.	Tonnages. Under upper-most deck.	Freeboard. By disc.	Freeboard. When last known.	Mean draught at sailing.	From
Foundered—1881.	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
"Verulam" . .	5	139·5	27·0	13·5	14 1	7	347	303	2 7	2 10	12 1	Mauritius .
Missing—1881.												
"Lightning" . .	18	210·8	35·0	23·0	24 1	9	1,249	1,087	4 0	...	...	New York .
"Hermes" . .	New	245·9	37·0	21·3	22 11	9½	1,464	1,332	4 0	...	...	Port Glasgow
Foundered—1882.												
"Llama" . .	25	147·0	28·7	18·0	19 2	7	474	474	3 2	...	14 9	Liverpool .
Missing—1882.												
"St. Maur" . .	24	212·0	36·0	25·7	27 6	9	1,486	1,430	4 6	...	23 1	Calcutta .
Foundered—1884.												
"Clwyd" . .	7	185·8	32·0	20·0	...	...	800	772	3 0	...	18 6	Cardiff . .
Missing—1885.												
"North American"	19	283·0	35·2	23·5	...	...	1,715	1,569	5 4	...	...	Melbourne .
"Shannon" . .	2	258·1	38·2	23·2	24 6	9½	1,690	1,531	4 11	...	...	London .
"Ellora" . .	9	221·2	35·1	21·2	...	...	1,198	1,056	4 6	...	...	Calcutta .
"Vancouver" .	16	209·7	33·5	21.9	...	...	1,109	990	4 1½	...	...	Cochin . .

E—*continued.*

VI.

General Cargoes (10 Vessels).

Voyage. To	Where lost.	*a.* Date of Sailing. *b.* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
London . .	N. Atlantic .	1881. *a.* 14 July. *b.* 23 Oct. .	12	1	...	...	Laden with 500 tons of cargo. Wreck Commissioner found that loss was due to the violence of gale she encountered. Masts were carried away, vessel thrown on beam ends and cargo shifted.
London . .	Not known .	*a.* 6 Nov. . *b.* ...	54	...	54	...	Laden with 158 tons of wheat, 955 tons of oil cake, 202 tons of slate, and 229 tons of general cargo. Not heard of after sailing. No inquiry held.
San Francisco .	Not known .	*a.* 3 Dec. . *b.* 4 Dec. .	26	...	26	...	Not heard of after being left by pilot off Rathlin on 4th December. The Court could not find any evidence upon which to form an opinion as to cause of loss. Laden with 600 tons of firebrick, 550 tons pig iron, 500 tons coke, and 250 tons of coal. The whole weight of cargo amounted to about 2,126 tons.
Callao . .	Off Brazil .	1882. *a.* 25 July . *b.* 10 Sep. .	14	...	...	...	Laden with a general cargo of 550 tons. No inquiry held.
Liverpool .	Not known .	1881. *a.* 18 Dec. . 1882. *b.* 4 April .	27	...	27	...	Not heard of after being signalled at sea on 4th April. The Court could come to no conclusion as to cause of loss. Laden with a general cargo of 2,500 tons.
Iquique . .	S. Pacific .	1884 *a.* 25 June. *b.* 4 Sep. .	17	...	3	...	Vessel met with terrific storms. Lost boats, was dismasted, and finally had to be abandoned. She had a general cargo of 1,200 tons.
London . .	Not known .	1885 *a.* 16 Feb. . *b.* 27 Feb. .	26	1	26	1	Not heard of after being spoken on 27th February. Vessel was supposed to have been in collision with ice, or with another vessel. Weight of cargo unknown.
Calcutta . .	Not known .	*a.* 27 Jan. . *b.* 10 Mar.	28	1	28	1	Not heard of after being spoken on the 10th March. Laden with 2,200 tons general cargo and 5 tons gunpowder. Inquiry Court could not find anything to account for loss.
London . .	Not known .	*a.* 20 Mar. *b.* 21 Mar.	25	1	25	1	Not heard of after leaving Sandheads on 21st March. No inquiry held. Laden with saltpetre, rice, seed and jute, in all 1,672 tons.
Havre . .	Not known .	*a.* 20 Mar. *b.* 29 Mar.	23	...	23	...	Not heard of after being spoken off Point de Galle on 29th March. Laden with 1,500 tons of oil, pepper, plumbago, coir, yarn, &c. Inquiry Court could not arrive at any conclusion as to cause of loss.

APPENDIX

TABLE

IRON SAILING SHIPS IN

NAME.	Age.	Registered dimensions.			Moulded depth.	Depth of keel.	Tonnages.		Freeboard.		Mean draught at sailing.	From
		Length.	Breadth.	Depth.			Gross.	Under uppermost deck.	By disc.	When last known.		
	Years.	Ft.	Ft.	Ft.	Ft. Ins.	Ins.			Ft. Ins.	Ft. Ins.	Ft. Ins.	
Missing—1881. "Tubal Cain" .	1	267·3	39·7	24·0	25 6	10	2,006	1,831	4 2	...	...	Singapore
Missing—1882. "Henrietta" . .	5	210·0	34·5	20·9	22 7	9	1,099	1,042	3 9	...	...	Hamburg
Foundered—1883. "Larkspur" . .	15	138·0	27·2	16·4	17 6	7	438	407	3 0	...	...	Cape Town
Missing—1883. "Kilmeny" . .	6	193·7	31·6	19·2	20 6	8	817	768	4 0	...	...	Wellington, N.Z. .
Foundered—1884. "Ettrickdale" .	12	238·4	36·5	22·1	...	...	1,345	1,251	4 4	...	...	Amsterdam
Missing—1884. "Amelia Ross" .	17	137·1	26·7	14·7	...	...	383	383	2 11	...	...	Callao . .
Missing—1885. "Alpheta" . .	11	196·5	31·7	18·4	...	...	864	797	3 4	...	...	Adelaide .

E.—*continued.*

VII.

BALLAST. (7 Vessels.)

yage. To	Where lost.	*a* Date of Sailing. *b* Date of loss or when last heard of.	Lives on board. Crew.	Lives on board. Passengers.	Lives lost. Crew.	Lives lost. Passengers.	REMARKS.
San Francisco .	Not known .	1881. *a.* 12 Aug.. *b.* 24 Aug..	35	...	35	...	Not heard of after being spoken off Sabtan Island on 24th August. No inquiry held. Description and weight of ballast unknown.
Newport, Mon.	Not known .	1882. *a.* 18 Oct. . *b.* 18 Oct. .	19	1	19	1	Not heard of after passing Cuxhaven on 18th October. No inquiry held. Description and weight of ballast unknown.
Mauritius .	Port Lewis Roadstead, Mauritius .	1883. *a.* Unknown *b.* 27 Sept.	13	...	8	...	The Mauritius Marine Board thought the loss was due to the master's indiscretion in throwing the whole of his ballast overboard in an open roadstead two miles from land, so that, while being towed in light, vessel was capsized in a squall.
Newcastle, N.S.W. .	Not known .	*a.* 6 May . *b.* ...	19	...	19	...	Not heard of after sailing. No inquiry held. Description and weight of ballast unknown.
Glasgow . .	North Sea .	1884. *a.* 10 Oct. . *b.* 11 Oct. .	22	2	22	2	Ballasted with 600 tons of sand that was not secured against shifting by properly fitted shifting boards. It was supposed, however, that the master, with the means on board at his command, could have taken proper precautions for preventing shifting. The vessel was last seen upon her beam ends, with yard arms touching the water. A violent squall came on, and when it cleared away the "Ettrickdale" had disappeared.
Talcahuano .	Not known .	*a.* 23 Feb. . *b.* ...	10	...	10	...	Not heard of after sailing. No inquiry held. Description and weight of ballast unknown.
ortland, Ore .	,, .	1885. *a.* 9 Sept. . *b.* ...	18	...	18	...	Not heard of after sailing. Description and weight of ballast unknown.

DISCUSSION.

Mr. Benjamin Martell (Member of Council): My Lord, I can only express the very great gratification which I have felt in listening to the Paper, and likewise that Professor Elgar has carried on the work, which he alludes to, that I began in the Paper read by me before the Institution of Naval Architects in 1860. The information which he has given us here is most important, and most valuable. We had a vast amount of statistics supplied to us by the Board of Trade when we were sitting on the Load Line Committee, but there was not time then to thoroughly digest this, which rendered such information less useful than it might have been. Professor Elgar has availed himself of this information, and he has thoroughly analysed and utilised it in the manner which he has set forth in these tables so as to enable us more clearly to ascertain the causes of the losses of different types of vessels, and thereby to put our fingers on the weak points to which he has referred. The inferences drawn I perfectly agree with, and particularly with that point which Professor Elgar draws attention to—the necessity of the stability of vessels being calculated before they proceed to sea. I do not think, however, as has been suggested elsewhere, that captains should have placed in their hands curves of stability, which it is perfectly impossible that they can either comprehend or make use of, but that this information might be practically supplied to them in the manner indicated here. That is to say, supposing a vessel to be loaded with a homogeneous cargo of a certain density, the captain might be informed what the margin of stability would be, and consequently the degree of safety in the ship, supposing the cargo to shift slightly, and the amount of cargo he should leave out 'tween decks, or the quantity of water ballast he might place in, so as to ensure a fair margin of stability. Useful practical information of that kind would be of great value to captains, and in many cases would ensure the safety of vessels, and prevent those lamentable accidents which we hear of. I do not think that it is creditable to the shipowning public to think that when they lay out the enormous amount of money which they do, and take the great care which they do to procure good, seaworthy and well built ships, that they will not go to the little additional expense of having this information supplied. I could excuse them in former times, because it was exceedingly difficult to get this information then, not having the class of men who were capable of making these calculations, but at the present time, fortunately, shipbuilders see the necessity of such knowledge, and I am surprised to see how their drawing offices are being improved by the supply of clever and intelligent draughtsmen who study these questions, and who are perfectly capable of making these calculations. It is only for the shipowners to request that it should be done, and to appreciate the value of it, and I am sure there will be no difficulty with regard to any vessel launched in getting that information. It would, I feel sure, be of enormous value in ensuring the safety of a ship under different conditions of loading. I put that forth, and I do hope it will be taken advantage of. It has been mentioned before, not once or twice only, but unfortunately it has received scarcely any more attention than was the case before the importance of it was brought before the public. In the Paper which I had the honour to read, and which Professor Elgar alludes to, I showed conclusively that ships of certain proportions and loaded as described, were almost bound to be lost if a trifling accident occurred with regard to the shifting of the cargo, or other cause affecting the stability. Although it is some years ago since I read that Paper, I have found from my own personal knowledge that shipowners pay very little more attention to the subject than they did then, with the exception of altering the proportions of their ships, and increasing the proportionate breadth somewhat, they do no more now than they did then.

However, I do hope that they will see the importance of it, and that every shipowner having ships engaged in over-sea voyages will see how very necessary it is that he should have this information supplied for the use of the captain for every ship he may have built. I do not think I have anything to say further than to return my thanks personally to Professor Elgar for the very great labour which he must have taken in the production of this Paper and for the very valuable information so ably placed before us which it contains.

Mr. W. H. White (Vice-President) : My Lord and Gentlemen, before the discussion closes I hope that we may have the opportunity of hearing shipowners speak, because I am sure that Professor Elgar's great desire will then be fulfilled. If his suggestions should be criticised, even adversely, with regard to the form in which information should be given for the guidance of those who have to manage ships, I am sure he will be delighted. I can quite confirm what Mr. Martell has said, that in the shipbuilding yards of this country there has been recently an enormous advance in scientific methods ; and in the endeavour, by means of calculation and experiment, to place in the hands of owners exact information as to the qualities of ships. Nine years ago, or thereabouts, I endeavoured to get together the best information then available as to the stability of merchant ships, and the result was extremely small—I could find but very few results indeed of inclining experiments. Four years afterwards I was flooded with information, thanks in a great measure to the action taken by Lloyds' management, and to the spread in the drawing offices of the country of trained men who are increasing in numbers every day, and who, with the help of the better instruments which are now available, can get through work which formerly was hopeless, under the conditions in which mercantile drawing offices have to be worked. In the Exhibition here, if I mistake not—the other day I saw attached to the stall of one of the shipbuilding firms specimens of these calculating instruments—integrators and planimeters, as well as specimens of the form in which this firm was accustomed to give information to owners of ships. I am confident that the shipbuilding firm which in that way indicates its practice in no sense stands alone. All over the country shipowners know that if they wish for information and are desirous to make use of it they can have it from the builders. But when they have got the utmost that the builder can give them, there still remains in their hands the power of life or death to the ship. That is the point which Professor Elgar has so clearly brought out. A merchant ship is not like a war ship—the designer does not dispose the weights. For that matter the owner has to accept enormous variations in the character and weight of the cargo carried, and all that the builder can do is to help the owner and captain to secure intelligent management in dealing with ships in their subsequent career. We want facts, Professor Elgar says, and I think he is quite right. We want facts thoroughly and intelligently analysed ; and he has given us an example here of how the analysis may well be conducted. I think everybody who has had to do with the investigation of losses of ships at sea must have been greatly struck with one fact, to which, although it is of a rather delicate nature, I may venture to allude, because I am not personally affected. I refer to the manner in which the official enquiries into the loss of ships are conducted, and more particularly to the manner in which what may be called the professional and scientific information is put before the Wreck Commissioner's Court and dealt with. I think that is a matter which requires to be taken in hand very firmly ; and unless I am very much mistaken, the Wreck Commissioner himself would heartily endorse that view of the case. There is always a suspicion that if any professional man comes into the Court to give evidence about a ship, he comes there because he is paid to come—that he is an "expert." An expert in some sense is discredited before he opens his mouth. That is very unfair—most unjust. I cannot conceive anybody, for the sake of the fee he might receive, coming into the Wreck Commissioner's Court and making a statement that he did not honestly believe to be true. These things are, however, sometimes said or

hinted at pretty broadly by the counsel on the other side. What is wanted, in my opinion, is that some impartial, possibly some official statement of the facts, so far as they can be disclosed, of the stability and the influence of the loading on the particular ship that has been lost, should be put forward, quite independent of either owner, builder, or underwriter. What has occurred to me is that the Board of Trade, being either in possession of, or in a position to obtain a great amount of information respecting ships lost, ought to have such a scientific and technical staff as could thoroughly investigate and put before the Court these facts, and the results of calculations based upon the facts, without expressing any opinion. Then it would be necessary to so constitute the Court that those who have to deal as assessors with this impartial statement of facts, should deal with them intelligently and capably. I do not want to reflect on the character of the present assessors to the Court, but one is doing them no injustice in saying that very often when questions of stability arise, the Court is not constituted in such a manner that these questions can be authoritatively dealt with, and I think that those who have been in the Court, or have read the proceedings of the Court, will not think I am overstating the case, when I say that in both directions to which I have referred there might be an improvement, viz.: in putting the facts of the case before the Court when it is a question of loading or stability, and in the constitution of the Court for such enquiries. Those enquiries ought to be conducted in such a manner as to exhaust all aspects of the subject, and if their results were published periodically, with full abstracts of the evidence in important cases, they would undoubtedly be of enormous advantage to the mercantile community and to the shipbuilders of the country. I for one hope that one result of this Paper may be that some movement in that direction may be made—I do not mean necessarily in the direction which I have suggested, but I think in some such way there might be an improvement in the constitution and the procedure of the Courts of Enquiry, so that the community may have put into its hands an unbiassed detailed analysis of the causes of loss.

Mr. H. H. West (Member of Council): My Lord and Gentlemen, unfortunately I have been so engaged this morning that I was not in the room during the reading of the whole of this Paper. I am therefore afraid that what I may say may not be very germane to the subject, but as your Lordship has called upon me I will mention a few points which occur to me. I notice that Professor Elgar has attacked this problem, as I expected he would do, from the stability side of the question. I think there is no doubt that where there is no direct information as to the cause of a loss at sea, insufficient stability may fairly be accepted as a probable cause of the loss, when known circumstances of the case point that way; yet I am not quite certain that we should take it for granted—and I do not think that Professor Elgar does take it for granted—in all cases, that the loss arises from want of stability. There are, unfortunately, too many cases of loss at sea where the cause of the loss is fully known, and it has been very ably pointed out, in some recent evidence before the Royal Commission on Loss of Life at Sea, that it is reasonable to suppose that losses, about which we have no definite information, arise from very much the same causes, and the causes operate in very much the same proportion, as in the case of losses of which we know the complete history. There is one point in connection with this question which strikes me very forcibly. We know that ships are abandoned at sea. We know also that when ships are abandoned the crew often have a very hard struggle for life, and in many cases, I think, we may imagine a ship being abandoned, and the crew lost subsequently. In that case the vessel that was abandoned would probably be a derelict and a waif on the surface of the water for a long time, and only eventually be lost by collision with some other ship. This makes two losses instead one; one an abandonment, the other a collision. Perhaps that might account for some of the losses that are recorded here. Of course, in assuming a missing ship to have been lost by

collision, there is always a difficulty in accounting for there being another missing ship in the same place, at the same time. I believe, however, that a careful study of the records of "last speakings" of missing ships, in the light of the suggestion I have made, would go far to meet this difficulty. In reference to these tables of Professor Elgar's, if he will allow me to suggest, I think that it would be of great advantage if he would add to them, before they are officially printed, the dates of sailing as well as the dates of loss. In the case of steamers particularly, I think that would be valuable information, as indicating approximately what was the condition of the coal consumption. That would help us on some points of stability as well as in other directions. I agree entirely with Professor Elgar as to the immense importance of dealing with the whole of these subjects before a ship goes to sea. As Mr. Martell has said, it is a matter of vital importance to the owners, to the underwriters, to the sailors, and to the whole community. One point, however, that occurs to me in connection with this question of stability is, that I am afraid we are apt to attach too much importance to the whole extent of the stability curve, and I am glad to see that Professor Elgar draws attention to that point, and mentions the fact of the earlier parts of the curve being of the greatest importance. Manifestly, when a ship is inclined to an extreme angle, there would be a point at which the whole conditions of the problem would be so altered by shifting weights, that the curve of stability in its original form would be of no practical value. I do not think I have anything further to add, except to say that I should very much like to hear the opinion of practical shipowners, of whom I see many in the room, and to hear what they have to say on the subject. They know a great deal about the practical working of the loading problem which would be exceedingly valuable information to us as scientific men, and if they would express their opinions I am sure we should all be very glad to hear them.

The Right Hon. Lord Brassey, K.C.B. (Vice-President) : My Lord Ravensworth and Gentlemen, I earnestly hope that this discussion will not close without some response to the appeal that has been made from the chair to those who can contribute the experience of this great port of Liverpool. But while some of the gentlemen from Liverpool are making up their minds to respond to the appeal from the chair, I will make a remark or two. My Lord, I would not pretend to criticise any part of the able Paper which has been read to us by Professor Elgar. All the conclusions which he deduces from his elaborate investigations commend themselves to my mind as being thoroughly sound and justifiable. If I could add anything to what has been said, I would point to the question of loading. Going about the sea as much as I do without at the same time possessing the scientific knowledge of the naval architect or the professional talent of the seaman, yet looking at what I see with an impartial mind, I am bound to say that I frequently see ships which appear extremely overladen. I look at Appendix D in the Paper in our hands, and I notice that in the first and second tables there are a very considerable number of vessels whose loss is attributed by the Wreck Commissioners to overloading. I know this is a most delicate point. Unless a ship carries a considerable cargo it is impossible for the business of the shipowners to be made remunerative. Even with the amount of cargo actually carried, we know very well that for a long period the business of shipowners has been very melancholy in its results, and it hardly seems practicable to suggest that less cargo should be carried than at present. I am bound, however, to say I am of the opinion that, in many cases, the cargoes carried are excessive. Anybody who has been at anchor as long as I have been in the Bosphorus, and seen steamers coming out in rapid succession from the Black Sea to the Mediterranean must be aware that the cases are by no means unfrequent in which vessels go to sea which are dangerously overladen. If it were possible to introduce a more universal recognition of the limits of loading, I would venture to hope that shipowners might be compensated by the reduced charges for

insurance. It is melancholy that the charges for insurance should bear so heavily on the shipping interest, and those charges would certainly be very much reduced if the loading was not carried to excess, and that fertile cause of loss avoided. I notice that a considerable number of vessels are lost with all hands from the spontaneous combustion of coal cargoes. I have no doubt that we have not yet reached perfection in the mode of dealing with the carriage of coal at sea. I myself had the privilege of rescuing the crew of a vessel off the coast of Patagonia. I know that this subject is an extremely difficult one, but there is no point to which science may be more appropriately directed than to this question of providing more effective means of ventilation, than now exist, in the case of ships employed to carry that description of coals which is demanded in almost all the ports of the west coast of South America. I do not wish to detain the meeting. I have pointed to two matters which have much impressed themselves on my mind—the question of loading and the question of ventilation of coal-laden ships. I earnestly hope that by this time some gentleman of Liverpool will have made up his mind to respond to the appeal from the chair.

Mr. Alfred Holt (Member): My Lord and Gentlemen, I rise with very great diffidence. I had made up my mind not to speak, and, except for the urgency that has been used to induce me to do so, I should not have made any remarks, for I did not come into the room in any degree prepared or with the idea that I should be called upon. I have an unready tongue, and am not able to put my ideas quickly and accurately into words, yet I feel that some matters, with regard to which I entertain clear opinions, though possibly opinions offensive to others with whom I have no quarrel, should be spoken of. Under these circumstances I feel that I ought to be well guarded in what I say, and I have also a right to stipulate that if anything falls from my lips which in any way conflicts with opinions firmly and conscientiously rooted in other people's minds I may have the power of revising my words, and also have due consideration extended to what I say. I am afraid that on the subject of loading I shall find myself in a minority of almost one, and such being the case, modesty would naturally have induced me to be silent; but, as I have been so strongly urged to speak, I must deliver my mind, and say that I have long entertained the opinion, and never more strongly than at present, that one of the greatest causes of loss of life is really that ships are loaded more deeply than they should be. This is no new opinion with me. I have differed throughout and at every step from the load-line legislation that has taken place, and I differ from its result *in toto*. I am convinced that it has caused vessels to be loaded more deeply than I think it is desirable they should be loaded, and more deeply than they would have been loaded except for this Commission. I believe that if the enquiry of the Royal Commission had not taken place, and their (as I think) unfortunate report had not been issued, we might have been saved from the position in which we now stand. Moreover, danger from deep loading is a question of degree, and I think that many losses which are not attributed directly to overloading would nevertheless not have occurred, or would have been less grievous, if the vessels had not been so deep. For instance, shifting of cargo when the vessel has a good deal of freeboard makes the possibility of saving her much greater than when she is very deep. With due deference to the great authorities who have made a pronouncement on the subject of load-line, I respectfully differ from them.

Another point on which I am afraid I shall dissent from the majority of my hearers, and one that I also advert to with equal diffidence, is the Wreck Commissioner's enquiries. I am firmly convinced that those enquiries have increased the loss of life at sea largely. I have watched them from the beginning. It may produce laughter, but mine is a deliberate opinion formed from observation, and not one that I am by any means pleased to have arrived at. It is, however, only

just that I should confess that of late I have not followed the subject so closely as I did at one time, partly owing to other more congenial occupations, and also because the subject has taken a course that I disapproved of, but was unable to influence. These enquiries are either apologies for bad loading, bad sailing or bad work of some description, or if the question be a difficult one they dodge it on the plea of the multiplicity of the cases. I believe the whole system of enquiry now pursued to be a mistake, and have faith in the old remedy at common law for those who suffer wrong. Though I advance these views with all deference to the opinions of others and with diffidence of my own, I have the satisfaction of knowing that many now in the room have in conversation expressed to me the same views, and some have not hesitated to express them in writing.

Another point on which I shall not differ so much, although I believe even on this there will be some moderate difference, is the desirability of scientific information about their ships being furnished to shipowners. Of course all information is desirable, but what is more desirable still is the disposition to apply it, and this has, I think, of late years become a lessening quantity. I know—every shipowner, especially a steamship owner, must know—the rapidity with which the loading of vessels is now carried on, and the very varying circumstances connected with that loading, how enormous weights have to be put in almost in any position at the last moment. This is compulsory in these hard days when the necessities of trade are quite different to what they once were. I am very much afraid that such information as has been alluded to, which I know well can be given by the multitude of trained draughtsmen now in existence, would really be of very little use. What would really be of use is the application of a few plain rules well known to every shipmaster or marine superintendent, and my point is that these are likely to be neglected under the shelter of delicate scientific information possibly not very completely understood.

I do not know that I have anything more to say. I have given opinions which have for years been slowly forming in my mind. If time had sufficed me to get my ideas a little more together, I might have stated them at length, and possibly I might have put them in a more forcible form, but to my mind these are the ideas that actually go to the heart of the question.

I conclude by repeating that it is almost with sorrow that I have spoken, and I should not have done so except for the urgency with which I was asked.

Mr. Martin Samuelson (Member): My Lord and Gentlemen, if you will allow me, I will say a few words on this subject, because it is a matter which I have had under consideration for a considerable number of years. I must say, to begin with, that I have been very much gratified by the Paper which has been read by Professor Elgar. I agree with him to a very considerable extent, and with all the results that he has produced before us to-day; therefore, my only object in rising is, to some extent, to confirm the remarks that have been made by Mr. White and also those which have just fallen from Mr. Holt. I have sat myself upon a Wreck Commission and have attended many in my time, and I believe that the Commission itself is improperly constituted. The Wreck Commissioner, no doubt, is a man of very considerable experience. He has legal ability, and having sat so long in the position he now holds, it has given him the opportunity of forming opinions on the various points which would be foreign to any stranger. At the same time I believe that those who sit with him are not proper people, or people who ought to be selected as assessors by the Board of Trade. They are very good sea captains and no doubt men of experience with regard to sailing ships, but men who know nothing whatever of the science of shipbuilding, and who, instead of guiding

the Wreck Commissioner, are guided by him. The Wreck Commissioner forms certain opinions, and those opinions are talked over with the assessors, and the assessors, as a rule, agree with Commissioner. I have disagreed with him and I have objected to sign the report which has been submitted to me, and I have written to the Board of Trade on the subject. I think it was Mr. White that suggested that some assessors should be appointed by the Board of Trade who could give a full report of what transpires at an enquiry before the Commission, and instead of having simply naval men, they should have proper scientific men who would sit as assessors with the Wreck Commissioner during the enquiries and who could form proper opinions. With regard to the stability of the ships, I hope I shall not give any offence to any shipbuilder in this room, but I am quite sure that if shipbuilders would take things more into their own hands, instead of leaving the qualification of ships in the hands of the shipowners, it would be very much better. I know from my own experience that a great many shipowners have peculiar views with regard to the construction of ships, which they like to have carried out, and I am sorry to say that competition in shipbuilding is so great that many shipbuilders, to please owners, take orders that they would not take if they were left entirely to their own conclusions with regard to the form which a ship should take. Young men in the profession are more apt to do this than old ones. I believe that if the matter was left in the hands of the shipbuilders, and if the shipbuilders were to give the loadline of the ship, it would be very much better not only for the shipowners themselves, but for the underwriters, and everybody connected with shipping. All respectable shipbuilders would fix such a load line as would make a ship perfectly safe, and they are the parties who are best able to judge where that load line should be. I do not wish further to take up the time of the meeting, but I desire to impress on the members these two points, one with regard to the composition of the Wreck Commission, and the second one with regard to the shipbuilders themselves If they were to take into their own hands the building of the ship, and decline to build any but what they knew to be a good and safe ship, we should hear of very much fewer wrecks than I am sorry to say we do at the present time.

Mr. E. Withy (Member) : My Lord, you have put me in rather an embarrassing position to begin with by calling upon me in such a prominent manner. I did not intend to speak upon this Paper, and do not know that I can say anything valuable in connection with it. There are many things which have been said that I can thoroughly endorse. I never believed that the Board of Trade had properly fulfilled their function, in having at their finger ends such an immense mass of statistics with regard to the loss of ships, and not analysing them as Professor Elgar has done. Several times at meetings in London I have said that it was an incomprehensible thing to me that the Board of Trade should be constantly bringing forward accusations in the way they did against shipowners and against particular types of ships, when by some careful analysis by competent people they could lay before the public an authoritative list of the different classes of loss. They would have the means also of getting from the builders of these ships, and from men who have investigated the subject, many authentic particulars which would throw light on the cause of loss. With regard to the Wreck Commissioner's Courts which have been mentioned, I have not appeared at very many of them, but quite agree that an expert is looked upon with some degree of suspicion in giving evidence. I have given evidence at one or two, and while I was certainly heard with some degree of respect, yet I felt perfectly clear in my own mind that whatever I said practically went into the waste paper basket of the inquiry. It is monstrous to suppose that any practical man who is engaged in making his living by the working out of contracts can spare time to go to such enquiries for the sake of the fee which he gets, because the fee itself is a most ridiculous compensation for the loss of time,

and inconvenience which he suffers in going. Again, I think there is very great value in shipbuilders giving to shipowners, and in shipowners carefully considering very full particulars of the qualities of the vessels which they will have to navigate. It is perfectly true that the best ships' seagoing qualities may be spoiled by bad loading, and there is, no doubt, a great deal of careless loading which is quite unavoidable; and on the other hand, it is true, as Mr. Holt pointed out, in the hurry of modern competition vessels must often have their loading completed at the last moment in anything but a satisfactory way in a very great number of cases. But what constructors and scientific people can do is to point out dangerous tendencies in the direction in which the *fashion* of shipbuilding is going. Many years ago I went strongly against the *fashion* of shipowners and the Board of Trade in preferring those narrow three-decked cargo boats now so generally condemned by scientific opinion. I do not mention this as claiming credit for being before other people in that respect, but for this purpose that constructors and scientific men (and especially now that they know so much more of the science and of making the necessary calculations) may point out directions in which it is very dangerous to pursue a particular class in building. I do not think I can add anything more that will be of value beyond endorsing some of those remarks which have been already made. I believe that the opinion amongst shipowners is gradually being influenced (more largely perhaps than we think) in the direction of avoiding dangerous types of ships at any rate, and if they will try to do their utmost in regard to loading, and the proper using of good ships when they get them, we shall hear less of losses in the future.

Professor F. Elgar, LL.D. (Member of Council): My Lord, I think there is very little remaining for me to say by way of reply in connection with the remarks that have been made. I am very pleased to find that the facts I have brought together, and the few disconnected remarks I have been able to make about them have been so well received. My object in preparing this Paper was to put upon record in our Transactions the leading particulars of recent losses, so far as they could be gathered out of Board of Trade and of other papers, and to arrange them in a form convenient for reference. With reference to Mr. West's suggestion that I should add to the tables another column showing when the ships sailed that were lost, I shall be very glad to get that done if possible; and I think it will be. I would like to point out before I sit down that there is one matter about which we seem to be pretty fully agreed, and that is that very great good might be done, if the particulars procurable respecting losses at sea could be collected together and published in a form that would be more complete and more available for the study of all who are interested in promoting the safety of ships than the present official returns. We hear a great deal about shipowners not having any desire to promote the safety of their ships and not caring to seriously study the matter. I have previously said before this Institution that my experience of shipowners does not confirm that view; but however desirous anyone might be to get full information upon, to thoroughly understand the subject, and to ascertain the chief causes of danger to ships, he is brought up by the great difficulty of extracting useful and accurate data from the present published returns, and of knowing what are the precise circumstances under which ships are lost. I think the meeting seems to be in accord upon that point. I have said in this Paper that I think more good might be done in the direction of publishing authentic, full, and intelligible information respecting losses than in any other way. There is one elaborate piece of machinery for inquiry into the causes of loss that has been referred to, and has been a long time in operation, and that is the Wreck Inquiry Court. That tribunal might be turned to very useful account in collecting the authentic particulars of losses, and in recording the best opinions that can be formed about them; but, for some reason or other, that is now done only in an imperfect

and unsatisfactory manner. This is not, perhaps, the fault of the persons who have to conduct the procedure of those Courts, but is rather the fault of the system upon which they are worked. Mr. White's remarks were very clear and decided upon that point, and my own opinions are so entirely in accord with what he said respecting the working of the Inquiry Courts, and the desirability of improving upon them, that in view of the little time we now have left, I will add nothing to them and be content with saying that I entirely endorse what Mr. White has said upon the matter. I have now only to thank the meeting for the very gratifying manner in which this Paper has been received.

The President: I am quite sure you will unanimously permit me to convey our united thanks to Professor Elgar for his lucid, exhaustive, and valuable Paper. There is only one observation I should like to make. The inference that I draw from hearing the Paper read and the remark that I am about to make cropped up from time to time in the discussion. It is the extreme, the objectionable misuse of statistics. Statistics are certain to mislead unless they are most carefully analysed and classified, and a great deal of the ill feeling that has been created, I am sorry to say, throughout the length and breadth of the country has arisen mainly from the misuse of statistics by persons in authority. There is one other observation which I will venture to make and that is that I entirely endorse the opinion already expressed by the highest authorities as to the value of accurate information being collected and disseminated as to the losses of ships. The value of that, not only to the shipping community and the commercial community, but to the Parliament of this country, which has to legislate on these technical and difficult subjects, cannot be overrated, and I entirely endorse that view. I am sure you will now allow me to convey your unanimous thanks to Professor Elgar for his very valuable Paper.

ON THE PROGRESS AND DEVELOPMENT OF MARINE ENGINEERING.

By William Parker, Esq., Chief Engineer-Surveyor, Lloyd's Register of British and Foreign Shipping, Member of Council.

[Read at the Twenty-seventh Session of the Institution of Naval Architects, at Liverpool, July 29th, 1886; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

At a meeting of the Institution of Mechanical Engineers, held in this City in 1872, Sir F. J. Bramwell read a very interesting Paper "On the Progress Effected in the Economy of Fuel in Steam Navigation considered in relation to Compound Cylinder Engines and High-pressure Steam."

In this Paper the history of the marine engine was traced from 1817 down to 1872, and it was shown that during the last nine years of that period the economy effected in the mode of making steam by the introduction of surface condensation, which obviated the direct waste of heat necessitated by continuously brining or blowing off part of the water from the boiler, combined with that resulting from the greater degree of expansion rendered possible by the adoption of compound engines working with higher steam pressures, had reduced the consumption of fuel in proportion to the power developed by more than one-half, or, in other words, during the period from 1863 to 1872, our marine engineers had doubled the working efficiency of the marine steam engine.

The immediate result of the great step in economy then attained was a large development of steam shipping, steamers being able to be profitably engaged in trades from which they were previously shut out, while larger and more powerful steamers took the place of the older ones on the passenger lines, and in the other trades in which steamers had previously been employed.

During the discussion on Sir F. Bramwell's Paper the late Sir Wm. Siemens, who was then the President of the Institution of Mechanical Engineers, said that, in his opinion, any further advance in economy should be looked for rather in the method of producing the steam than in further extending its expansive action. This opinion, however, has not been justified by events, as a further considerable advance in economy has already been attained by improvements in the methods of using steam, while little, if any, improvement has yet been made in the methods of producing it.

In 1881, Mr. F. C. Marshall, of the firm of Messrs. R. W. Hawthorn, Leslie & Co., of Newcastle-on-Tyne, read a Paper at a meeting of the same Institution, at Newcastle, "On the Progress and Development of the Marine Engine," in which it was shown that since the reading of Sir F. Bramwell's Paper, a further economy of 13·3 per cent. had been effected, the advance being wholly due to the use of higher steam pressures.

Since that time a still further improvement has been made by the introduction of even higher steam pressures, and of triple and quadruple expansive engines, for the proper utilization of these higher pressures; but up to the present little, if any, improvement has been effected in the method of making the steam, the marine boiler of the present day being almost exactly what it was in 1872, except, of course, that it has been possible to make it stronger than was then deemed to be practicable, owing to our having command of improved materials and appliances.

It is, of course, difficult to foresee what the future has in store for us, or to be sure of anything, except that there is no finality in invention; but, in my opinion, there are good reasons for believing that, so far as the use of steam is concerned, that is to say, the conversion of the heat of the steam into work by means of the engine itself, there is not now so much room for improvement as there appears to be in the other operations of transferring the heat of the combustion of the fuel into the steam, or of applying the work of the engine when it has been produced to its useful purpose of propelling the vessel. A very considerable portion of the heat of combustion of the coal still disappears up the funnels of all our steamers, doing no useful work, except producing the necessary draught, which could be produced mechanically with very much less heat, if only the funnel heat could otherwise be usefully employed, while there still remains a wide field for improvement by the production of more nearly perfect combustion of the fuel in the furnaces themselves.

In regard to the economical application of the work, after it has been produced, to the propulsion of vessels, there is also room for great improvement, for, according to the late Mr. Froude, the greatest authority upon this subject, only about one-half of the total power exerted by the engines is effective in propelling the vessel, the remainder being dissipated in overcoming frictional and other resistances. Advance in this direction will, I think be attained more from the results of direct experiment than from theoretical considerations. Already some marked improvements resulting from experiments with screw propellers have been made in some few isolated cases in which the performances of the screws first fitted were considerably below the expectations of their designers, and in these days when such immense powers are exerted in our large and fast ocean passenger vessels it is very probable that the cost of a few experimental screws would soon be repaid by the economy of power they would effect.

It must not be inferred that because the marine boiler of the present day is practically

dentical in design with that of 1872, except, so far as regards strength, no attempt has been made to improve it. As a matter of fact, very many experiments in this direction have been made, and to show this I have only to mention the Rowan, the Howard, the Roots, the Jordan, the Perkins, the Herreschoff, and the Turner boilers, besides others in which brick combustion chambers, brick furnaces, etc., have been used. All these forms, however, have either completely failed or have given so much trouble at sea, from their inability to fulfil the requirements incidental to ocean steaming, that none of them are likely to be repeated. Most of them were designed more with the view of enabling high steam pressures to be safely carried than with the idea of obtaining a high evaporative efficiency, and in the six first mentioned types they mostly consisted of tubes or of cylindrical portions of relatively small diameter, which consequently possessed great strength, even when made of comparatively thin material. The small dimensions of the parts, however, materially assisted in rendering them unsuitable.

The introduction of steel as a material for boiler plates, and the use of a stronger form of furnace than the plain cylindrical one, combined with improvements in manufacture, have now admitted of steam pressures of 150 to 180 lbs. per square inch being safely carried in boilers of the ordinary type, so that there will be now no incentive for engineers to design these novel types of boilers so far as strength is concerned, unless it can be shown that there is reasonable grounds for supposing that steam of still higher pressures, viz., from 250 to 300 lbs. per square inch, can be conveniently and economically used. I shall return to this point further on, but in the meantime I must express my conviction that if we find in the immediate future, in regard to boilers, any departure from our present practice, the step will not be made solely on account of obtaining higher steam pressures, but will be made principally, if not entirely, with the view of obtaining greater evaporative efficiency.

The first engines made for sea-going purposes on the triple expansive principle were those made in 1874 from the designs of Mr. A. C. Kirk, now of the firm of Messrs. R. Napier and Sons, for the S.S. "Propontis," owned by Mr. W. H. Dixon, of this city. These engines were made with three cranks, and were supplied with steam by means of one of the types of boilers I have mentioned, viz., Rowan's Patent, and during the limited time that the boilers worked satisfactorily they proved themselves to be very efficient. Unfortunately, the boilers failed, two out of four having exploded disastrously at sea. They were replaced by others of the ordinary type working at what was at that time considered to be a very high pressure, viz., 90 lbs. per square inch, and the engines, of course, did not give quite such good results at that pressure as they had done at the pressure for which they were designed. This, however, was not their fault, and I believe they are still at work and are giving great satisfaction, being now supplied with steam of 160 lbs. pressure from another set of boilers. These engines should, therefore, be regarded with great interest as being the parents of what is now becoming the common engine of the day.

The next triple expansion engines were those of the yacht "Isa," designed by Mr. A. Taylor, of Newcastle-on-Tyne, and built in 1877. These were constructed to work upon two cranks only, the high and intermediate cylinders being tandem. They were supplied with steam of 120 lbs. pressure, from a boiler of the ordinary type, the comparatively small dimensions of the boiler enabling this pressure to be carried without difficulty. These engines were very successful, but seeing that they were fitted in a yacht and were therefore not working continuously, and were, moreover, of comparatively small power, they did not excite so great an interest in the engineering world as might have been expected, and it was not until 1881 that the problem of economic propulsion advanced a further stride by the "Aberdeen," built for Messrs. G. Thompson and Co., of London, showing conclusively that the triple expansion engines were capable of working continuously on long ocean voyages with complete satisfaction.

The engines of the "Aberdeen" were made by Messrs. R. Napier and Sons, after the general design of those of the "Propontis." They are supplied with steam at a pressure of 125 lbs. per square inch by two steel double-ended boilers, each 14 ft. diameter, and they have until now worked regularly and satisfactorily upon the longest voyages, and have given no trouble whatever, beyond the ordinary wear and tear incidental to engines of the same power, the high steam pressure involving no more difficulties either with the boilers or engines than would have been experienced with a pressure of 75 or 80 lbs. per square inch, working under the same conditions.

Since the "Aberdeen" commenced running there have been at least 150 sets of triple expansion engines made for the British mercantile marine, while about 20 sets of ordinary compound engines have been altered into triple expansion when they have had new boilers fitted to them.

During the present half year there have been no less than 41 sets of triple expansion engines built, as compared to 60 pairs of compound engines, and there are at present 128 sets of triple expansion engines building, as compared to 71 pairs of compound, independent of those building for the British and Foreign Navies. For the British Royal Navy there are 20 sets being built, expected in the aggregate to indicate 130,000 horse-power.

It is difficult to obtain absolutely reliable information as to the performances of these vessels, but the above statement is, I think, conclusive proof that the economy obtained by using this type of engine instead of the two cylinder compound is very appreciable, otherwise it is difficult to account for the very rapid rate at which the new type has superseded the other in practically all new vessels. I can, however, give the following particulars of the actual work done by some steamers fitted with triple expansion engines, and others that have been converted from ordinary compound engines to triple expansion engines; these particulars having been obtained from reliable sources, speak for themselves.

Two large passenger steamers of over 4,500 gross tonnage, having engines of about 6,000 indicated horse-power, built of the same dimensions, from the same lines, with similar propellers, are exactly alike in every respect except so far as their machinery is concerned. One vessel is fitted with triple expansion engines, working at a pressure of 145 lbs. per square inch, whilst the other vessel is fitted with ordinary compound engines, working at a pressure of 90 lbs. per square inch. Both vessels are engaged in the same trade, and steam at the same rate of speed, viz., 12 knots per hour. The latter vessel on a round voyage of 84 days, burns 1,200 tons more coal than the former.

The performances of the next two vessels I am about to quote do not compare on a question of decreased consumption, but on one of enhanced carrying capacity, with an equal speed, and the same consumption of coal.

The first vessel has a gross tonnage of about 2,220 tons, and is, comparatively speaking, a modern type of ship. She is fitted with ordinary compound engines, working at a pressure of 90 lbs. per square inch, and carries, when fully loaded, 3,000 tons of cargo, including bunker coal. She steams 10 knots per hour, and burns 20 tons of coal per day. The second vessel has a gross tonnage of 2,800 tons, was built last year, and fitted with triple expansion engines, working at a pressure of 150 lbs. per square inch. She makes the voyage to India in the same length of time as the former vessel, burns the same amount of coal, viz., 20 tons per day, and carries 4,200 tons, or 1,200 tons more cargo with the same working expenditure.

The next case I will take is that of a mail steamer, the engines of which have been converted from ordinary compound to triple expansive, the propeller not being altered. The vessel is of 3,500 tons gross register, both ship and engines having been built by one of our leading builders. She was originally fitted (in 1871) with ordinary compound engines, working at a pressure of 60 lbs. per square inch. These have been altered into triple expansion engines, and new boilers have been fitted working at 150 lbs. per square inch. The vessel still maintains her original speed, and the consumption of coal has been lessened 25 per cent.

In the case of another mail steamer, the engines of which have been altered in a similar manner, I have compared her present performances with those of ten previous voyages, and find that the decrease in consumption is 33 per cent., while the same speed is maintained.

In these cases the consumption quoted includes the coals used for galley, steering engine, and other purposes, so that the economy gained in the main engines is greater than that given by these figures.

The following table gives the names of a number of British Merchant steamers fitted with triple expansive engines, together with the dimensions of the engines, boiler pressures, &c. :—

Date.	Name.	Engines.						Steam Pressure.	Builders.	Owners.
		No. of Cylinders.	Diameters.				Stroke.			
1874	Propontis	3	23	41¼	62⅛		42	150	J. Elder	W. H. Dixon.
1881	Aberdeen	3	30	45	70		54	125	R. Napier & Son	G. Thompson & Co.
	Claremont	3	14¼	20¼	40		33	150	Douglas and Grant	Fisher, Renwick & Co.
1882	Draco	3	21	32	56		36		Earle's Co.	T. Wilson, Sons & Co.
	Hidalgo	3	22	32	60		33		Amos and Smith	T. Wilson, Sons & Co.
	Yeddo	3	25	33½	67		36			T. Wilson, Sons & Co.
1883	Bassano	3	21	35	67		36	150	C. D. Holmes	T. Wilson, Sons & Co.
	Isle of Dursey	3	15¾	22	44		33	150	Wallsend Slipway Co.	Dixon, Robson & Co.
	Oaxaca	3	40	64	92		60	135	R. Napier & Son	
	Rosario	3	20½	33	58		36	150	Earle's Co.	T. Wilson, Sons & Co.
	Tamaulipas	3	40	64	92		60	135	R. Napier & Son	
1884	Arabian	4	9	9	18	32	22	150	Rankin & Blackmore	Morton & Williamson.
	Arawa	4	37	61	71	71	60	160	Denny & Co.	Shaw, Savill & Albion Co.
	Ashton	3	22	37	58		36	140	T. Richardson & Sons	Manchester, Sheffield & L. Ry. Co.
	Australasian	3	32	46	70		54	125	R. Napier & Son	G. Thompson & Co.
	Burgos	3	20	33	54		36	160	Blair & Co.	H. Briggs, Sons & Co.
	Chester	3	22	37	58		36	140	T. Richardson & Sons	Manchester, Sheffield & L. Ry. Co.
	County of York	4	20	28½	40	57	42	164	Barrow S. B. Co.	Taylor, Abrahams & Co.
	Dynamo	3	17	27	48		27	150	Earle's Co.	T. Wilson, Sons & Co.
	Electro	3	18	27	48		27	150	Earle's Co.	T. Wilson, Sons & Co.
	Finland	3	20	32	56		36	150	Earle's Co.	G. R. Sanderson & Co.
	Lizzie	3	18	31	50		33	150	T. Richardson & Sons	J. Covedale & Son.
	Longnewton	3	20½	34	55		33	140	T. Richardson & Sons	Marquess of Londonderry.
	Loodiana	4	26½	44	51	51	51	160	Denny & Co.	British India S. N. Co.
	Martello	3	31	50	82		57	150	Earle's Co.	T. Wilson, Sons & Co.
	Mexico	3	40	64	92		60	135	R. Napier & Son	
	Mosquito	3	11½	17	30		18		Earle's Co.	T. Wilson, Sons & Co.
	Para	3	19	35	53		33	150	T. Richardson & Sons	G. Steel & Co.
	Shagbrook	3	22	30	60		36	150	Wallsend Slipway Co.	Harris & Dixon.
	Swift	3	21	32	56		30		E. Wales	W. H. H. Hutchinson & Son.
	Tainui	4	37	61	71	71	60	160	Denny & Co.	Shaw, Savill & Albion Co.
1885	Actor	3	20	33	54		36	160	Blair & Co.	T. & J. Harrison.
	Akaba	3	27	45	74		48	170	Blair & Co.	J. M. Wood.
	Alexandra	3	11½	17	30		21	150	Earle's Co.	Hull & Barnsley Railway Co.
	Algoma	3	26	42	66		42	142	T. Richardson & Sons	Alleghany S.S. Co.
	Amana	3	24	40	65		48	160	Blair & Co.	J. M. Wood.
	Ariel	3	23	35	60		57	150	Earle's Co.	E. Leetham.
	Baghdadi	3	21½	33	55		39	150	Wigham Richardson	Persian Gulf S.S. Co.
	Barco	3	25	41	68		48	160	Denny & Co.	Queensland S.S. Co.
	Bengal	3	35	56	89		66	145	Caird & Co.	Peninsular & Oriental S. N. Co.
	Beresford	3	21	35	57		36	148	T. Richardson & Sons	G. Horsley.
	Bonito	3	10½	15	27		16	140	W. B. Thompson	Lowestoft S. C. Fishing Co.
	Bradley	3	13	19	35		24	150	N. E. Marine Co.	R. Thornman.
	Brentford	3	21	35	57		39	160	Blair & Co.	Britain S S. Co.
	Buffalo	3	33	54	86		60	160	Palmer's Co.	T. Wilson, Sons & Co.
	Burrumbeet	3	23	33	60		42	150	Wallsend Slipway Co.	Huddart, Parker & Co.
	Cairndhu	3	18½	30	48		36		Blair & Co.	T Cairns.
	Chelydra	3	24	39	64		42	145	T. Richardson & Sons	Angier Bros.
	Ching-Wo	3	26	42	66		42	142	T. Richardson & Sons	China S. M. S. N. Co.
	Coot	3	19½	32½	53		36	150	Central M. E. Co., Ld.	Cork S.S. Co.
	Congella	3	21	34	56		42	150	G. Clark	Bullard, King & Co.
	Corangamite	3	23	35	60		42	150	Wallsend Slipway Co.	Huddart, Parker & Co.
	Coromandel	3	35	56	89		66	145	Caird & Co.	Peninsular & Oriental S. N. Co.
	Curlew	3	13	19	36		24	150	Walker Henderson	J. Hay & Sons.
	Dragoman	3	24	39	64		42	150	Wallsend Slipway Co.	Bedouin S. N. Co.

Date.	Name.	Engines. No. of Cylinders.	Diameters.				Stroke.	Steam Pressure.	Builders.	Owners.
1885	Dundee	3	26	43	70		42	165	Gourlay, Bros. & Co.	Dundee, Perth & L. S. C.
	Eastwood	3	19½	30	52		33		Earle's Co.	G. R. Sanderson & Co.
	Editor	3	20	33	54		36	160	Blair & Co.	Charente S.S. Co.
	Eldorado	3	26	40	68		39		Earle's Co.	T. Wilson & Sons.
	Emilie	3	21	34	56		36	160	Blair & Co.	Burdick & Cook.
	Enfield	3	21	35	57		39	160	Central M. E. Co., Ld.	Pyman Bros.
	Eveline	3	18½	31	50		36	160	Wallsend Slipway Co.	Pyman, Bell & Co.
	Fernlands	3	21	35	57		39	150	Central M. E. Co.	Hardy, Wilson & Co.
	Flamboro	3	22	35	58		42	150	Palmer's Co.	Bowser, Ormston & Co.
	Flamingo	3	15½	24	40		24	140	Earle's Co.	Gt. Grimsby Ice Co.
	Formosa	3	20½	32	53		36	150	Wigham Richardson	Douglas S.S. Co.
	General Gordon	3	15	24	40		36	160	A. Stephen & Son	Maclay & M'Intyre.
	General Gordon	3	26	41	60		42	135	A. & J. Inglis	Dublin & Glasgow S. P. Co.
	Greystoke	3	21	35	56		36	142	T. Richardson & Sons	R. Ropner & Co.
	Hajeen	3	24	39	64		42	150	Wallsend Slipway Co.	Bedouin S. N. Co.
	Haswell	3	16	26	43		36	150	Wallsend Slipway Co.	J. Fenwick & Sons.
	Heliades	3	24	40	64		45	150	T. Richardson & Sons	R. P. Houston.
	Holland	3	11½	17	30		21	150	Earle's Co.	Boston D. S. Fishing & I. Co.
	Inishtrahull	3	25	37	58		48	135	D.&W. Henderson&Co.	Clyde Ship. Co.
	Isle of Hastings	3	20	33	53		36	150	Black Hawthorn	Dixon, Robson & Co.
	J. M. Smith	3	21	36	57		36		T. Richardson & Sons	J. Westall.
	J. R. Hinde	3	16½	26	43		36	150	Palmer's Co.	J. Fenwick & Sons.
	James Joicey	3	16½	26	43		36	150	Palmer's Co.	J. Fenwick & Sons.
	Kaisow	3	30	47	75		48	144	T. Richardson & Sons	China S. M. S. N C.
	Kesteven	3	11½	17	30		21	150	Earle's Co.	Boston D. S. Fishing & I. Co.
	Knight Errant	3	27	44	71		48	150	Palmer's Co.	Greenshields, Cowie & Co.
	Knight of St. John	3	27	44	71		48	150	Palmer's Co.	Greenshields, Cowie & Co.
	Lalpoora	4	26½	44	51	51	51	160	Denny & Co.	British India S. N. Co.
	Lawada	4	26½	44	51	51	51	160	Denny & Co.	British India S. N. Co.
	Lee Sang	3	23	33	50		39	125	Lond. & Glasgow Co.	Indo-China S. N. Co.
	Libra	3	11½	17	30		18	140	Earle's Co.	Sea Stm. Trawl. Co.
	Lindsey	3	11½	17	30		21	150	Earle's Co.	Boston D. S. Fishing & I. Co.
	Mararoa	3	31	51	84		54	160	Denny & Co.	Union S.S. Co. of N. Zealand.
	Mary Nixon	3	16½	26	43		36	150	Wallsend Slipway Co.	J. Fenwick & Sons.
	Matabele	3	19	30	50		36	150	Hall, Russell & Co.	J. T. Rennie & Son.
	Mequinez	3	20¼	33	54		36	150	G. Clark	Mersey S.S. Co.
	Meriddio	3	18½	30	48		36	160	Blair & Co.	Marshall, Dodson & Co.
	Newcastle	3	18½	30	50		36	160	N. E. Marine E. Co.	J. J. & C. M. Forster.
	Norkoowa	3	20	33	53		36	150	Black Hawthorn&Co.	M'Ilwraith, M'Eachan & Co.
	Ocean Prince	3	20	33	54		39	150	J. Dickinson	Prince S.S. Co., Ld.
Lost.	Palala	3	21	34	56		42	150	G. Clark	Bullard, King & Co.
	Port Victor	3	27	42	70		48	150	Wigham Richardson	W. Milburn & Co.
	Power	3	15	23	40		25	150	Newall & Co.	Callier Bros.
	Preston	3	21	35	57		39	160	Blair & Co.	R. Ropner & Co.
	Restitution	3	29	44	74		48	150	Wigham Richardson	R. Conaway & Co.
	Royal Prince	3	20	33	54		39		J. Dickinson	Prince S.S. Co., Ld.
	Seagull	4	19	19	40	60½	72	150	Hall, Russell & Co.	India G. S. N. C.
	Shakespear	3	21	34½	55½		36	145	T. Richardson & Sons	Glover Bros.
	Snowdrop	4	7½	15	27	27	16	140	W. B. Thompson	W. H. Burn.
	Stella	3	22	37½	60		39	143	T. Richardson & Sons	Herskind & Woods.
	Suez	3	21	35	57		39	160	Blair & Co.	T. Appleby & Co.
	Swallow	3	13	21	40		24		E. Wales	W. H. H. Hutchinson.
	Swiftsure	3	20	33	61		36	144	T. Richardson & Sons	Christie & Co.
	Torpedo	3	14½	22	36		24		Earle's Co.	T. Wilson, Sons & Co.
	Transition	3	20	33	54		36	160	Blair & Co.	J. M. Lennard & Sons

Date.	Name.	Engines. No. of Cylinders.	Diameters.				Stroke.	Steam Pressure.	Builders.	Owners
1885										
Lost.	Tunstall	3	25	40	66		45	150	J. Dickinson	J. S. Barwick.
	Virgo	3	11½	17	30		18	140	Earle's Co.	Grimsby & N. Sea S. Trawl Co.
	Washington City	3	23	37	60		36	145	T. Richardson & Sons	C. Furness.
	Wells City	3	21½	36	57		36	140	T. Richardson & Sons	C. Hill & Sons.
	Willesden	3	21	35	57		39	160	Blair & Co.	Britain S.S. Co.
	Witham	3	11½	17	30		21	150	Earle's Co.	Boston D. S. Fishing & I. Co.
1886	African	3	21	34½	55½		36	150	T. Richardson & Sons	Union S.S. Co.
	Alcides	3	29	43	68		54	150	J. & J. Thompson	Donaldson Bros.
	Anglian	3	26	42	69		42	150	T. Richardson & Sons	Union S.S. Co.
	Cleveland	3	21	35	57		39	150	Centr. Marine E. Co.	W. Taylor.
	Clitus	3	23½	37	61		42	150	Palmer's Co.	A. Currie.
	Condor	3	11	16½	30		21		Cox & Co.	W. & T. Rowe.
	Dalhousie	3	10½	15	27		16		W. B. Thompson	W. B. Thompson.
	Danube	3	15	23	38		24		D. J. Dunlop & Co.	London & Tilbury L. Co.
	Dunbrodie	3	24½	39	62		42	150	Lond. & Glasgow Co.	Waterford S.S. Co.
	Eddystone	3	23	37	58		48	135	W. B. Thompson	Clyde Shipping Co.
	Euterpe	3	24	42	69		48		T. Richardson & Sons	Austro-Hungarian Lloyds.
	Fijian	3	18½	31	49		36	150	Palmer's Co.	G. W. Nicoll & Co.
	Gloamin	3	19	30	50		42	170	Hall, Russell & Co.	R. A. Mudie.
	Hubbuck	3	27	42	69		43	150	T. Richardson & Sons	W. Lund.
	Inishowen Head	3	24½	37	64		48	160	Harland & Wolff	Ulster S.S. Co.
	Iran	3	28	43	77		51	160	Harland & Wolff	E. P. Bates.
	Jumna	4	35	48½	67	94	60	160	Denny & Co.	
	Lahora	4	24	34	48	68	48	160	Denny & Co.	
	Libra	3	25	42	67		42	150	Wallsend Slipway Co.	Gen. St. Nav. Co.
	Loch Etive	3	21½	34	56		42	165	Gourlay, Bros. & Co.	Dandee Loch Line S.S. Co.
	Lusitania	3	36	60	96		48	150	T. Richardson & Sons	Orient S. N. Co.
	Mandalay	3	20	33	54		36	160	Blair & Co.	T. Turnbull & Son.
	Mercedes	3	21	35	57		39	160	Blair & Co.	Adamson & Ronaldson.
	Monmouthshire	3	30	47	70		51	140	London & Glasgow	D. J. Jenkins & Co.
	Northenden	3	21½	35	57		39		Wallsend Slipway Co.	Manchester, Sheffield & L. Ry. Co.
	Orizaba	3	40	66	100		72		Barrow S. B. Co.	Pacific S. N. Co.
	Paumben	3	18	30	48		36	160	A. McMillan & Son	
	Port Pirie	3	29	44	74		48	150	Wigham Richardson	W. Milburn & Co.
	Powhatan	4	18	38	60		42		Barrow S. B. Co.	Mediter. & New York S. S. Co.
	Racer	3	15	23	40		27	150	Carr & Co.	Queenstown Tug Co.
	Roseland	4	6	9	16		12		Cox & Co.	St. Mawes S. P. Co.
	Saint Fillans	3	24½	37	64		48	160	Harland & Wolff	Rankin, Gilmour & Co
	Saint Oswald	3	24	39	64		42	150	Wallsend Slipway Co.	Rankin, Gilmour & Co.
	Satellite	6	10½	16	26		22	150	D. J. Dunlop & Co.	Hon. Corp. Trinity House.
	Scholar	3	20	33	54		36	160	Blair & Co.	T. & J. Harrison.
	Teresa	3	18	30	48		36	155	A. McMillan & Son	
	YACHTS.									
1877	Isa	3	10	16	28		24	120	Douglas & Grant	E. C. Healey.
1885	Mohican	3	18	27	43		33	140	D. & W. Henderson	J. & W. Clark.
	Nerissa	3	13	21	35		30	160	A. Stephen & Son	A. Stephen.
1886	Cassandra	3	9	14	22		15	150	Kincaird & Co.	J. G. Clark.
	Fire Fay	3	15	30	18	42	24	150	Lobnitz & Co.	
	Morven	3	14	22	40		30	180	Caird & Co.	J. T. Caird.
	Oimara	3	11	16	28		22		J. Reid & Co.	N. Mathieson.
	Rionnag-na-Mara	6	3 of 7	16	22	34	24	180	Rankine & Blackm.	A. G. Pirie.
	Vanduara	3	13	20	33		24	160	D. & W. Henderson.	
	Warrior	3	16	24	40		24	150	Bailey & Leetham	W. S. Bailey.

It will thus be seen that during the last five years marine engineers have not been idle, for even if we do not consider the full gain of 33 per cent. which is usually claimed to have been fully demonstrated, but merely acknowledge an economy of 25 per cent. as having been attained, it will be evident that the fact that three tons of coal are now able to do the work which it used to require four tons to perform, will have an important influence upon the future of our steam shipping. And I venture to predict that shipowners will not be slow in availing themselves of the opportunity that engineers have provided for them, and that we shall shortly see very many of the engines of our commercial marine, which are in good condition, converted into the newer type.

This conversion may be made in at least three different ways : 1st. By adding another cylinder and crank, necessitating an addition to the bed plate, and therefore also to the length of the engine room. This method will most probably in all cases necessitate the removal of the present cylinders and the fitting of three new ones of proper proportions. 2nd. By adding another cylinder to the top of either the present high or of the low pressure cylinder, necessitating no great structural alteration to the engines, but possibly requiring the present low pressure cylinder to be fitted with a liner to somewhat reduce its diameter. 3rd. (And this is the solution of the problem most favoured by many engineers) by replacing the two present cylinders by four new ones, thus making a tandem arrangement to each crank and converting the engine into one of the quadruple expansion type.

Whichever method is adopted, it must be remembered that the economy obtained in the triple expansion engine is not obtained by merely making the steam work successively in three cylinders irrespective of other considerations. The economy is obtained primarily by utilizing the principle of expansion to as great a degree as is practicable, but, as I pointed out in a Paper "On the economy of compound engines," which I read before the Members of this Institution at London, in March, 1882, there must be a limit to which expansion can be beneficially carried in two-cylinder engines, on account of the condensation of the steam in the cylinders, induced by the great range of temperature to which they are continually being subjected, and there is consequently a similar limit to which it can be economically carried in triple expansive engines; any further increase of expansion beyond which will necessitate the use of four cylinders, if it is to be carried out economically.

There is, however, another point as to expansion, which deserves consideration. It is in not carrying expansion to a sufficient extent, and so discharging the steam into the condenser before it has effectively done its work. This matter, if not specially pointed out, is likely to deceive the uninitiated, who would perhaps conceive an engine so working to be a better one than another of superior design, simply because it would be doing a greater amount of work in proportion to its size.

In order to fully utilize the principle of expansion, it is necessary to have engines of

sufficient size for the steam to fully expand into, and so relatively large engines will be, within proper limits, more economical than smaller ones doing the same amount of work. To show this I will refer to two sets of indicator diagrams (see Plate XI) taken from two engines made by two well-known engineering firms, who have each attained celebrity for the excellence of their productions, yet a comparison of the results obtained in the two cases shows a marked difference between the two engines. I should state that in each case the diagrams were taken from the engines on the trial trips. In engine No. 1, the cylinders are proportioned as 1 : 2·5 : 7·11 ; the boiler pressure is 150 lbs. per square inch, and the mean pressure of the three cylinders reduced to the low pressure cylinder is 25·61. In engine No. 2, the cylinders are proportioned as 1 : 2·5 : 5·28, the boiler pressure is 135 lbs. per square inch, and the mean pressure reduced to low pressure cylinder is 32·10 lbs. per square inch. It will be seen at once that engine No. 2 is not using the steam so expansively as engine No. 1, and in proportion to the size of low pressure cylinders it is doing $\frac{32 \cdot 10}{25 \cdot 61}$ or 1·253 times as much work as No. 1. On measuring the amount of steam used per revolution, as shown per indicator diagrams, it will be found, however, that engine No. 2 is using 1·494 times as much weight of steam as engine No. 1, and as it is only doing 1·253 times as much work, the efficiency of No. 1 engine must be $\frac{1 \cdot 494}{1 \cdot 253}$, or 1·19 times greater than that of No. 2, in other words No. 1 engine would give 19% more power than No. 2, from the same weight of steam used.

I am aware that these figures cannot all be taken as being mathematically correct, for as I pointed out in the Paper referred to, there must always be some condensation of steam in all engines, so that a greater weight of steam is used than can be measured upon the indicator diagrams, and no doubt there is somewhat greater condensation in engine No. 1 than in No. 2, but the difference from this cause cannot nearly be so great as 19%, so that it remains that one engine is very much more economical than the other. It may perhaps be simpler to say that engine No. 2 is being overworked.

To show more clearly the effect of the internal or cylindrical condensation upon the efficiency of the engine it will perhaps be interesting to refer to Figure 3. It is known from theoretical considerations that supposing no practical difficulties intervened to prevent its realization, the utmost efficiency possible with a steam engine would be represented by the difference between the temperature of the boiler steam and that of the condenser divided by the absolute temperature of the boiler steam. This ideal efficiency for steam of various pressures, assuming, as is usual, the condenser temperature to be 100°, is shown by the curved line in Figure 3. It will be seen to rise slowly as the pressure increases, being ·261 at 50 lbs., ·270 at 60 lbs., ·298 at 100 lbs., ·321 at 150 lbs., ·339 at 200 lbs., ·353 at 250 lbs., and ·365 at 300 lbs. per square inch.

The actual efficiencies of steam engines, in practice, must, for several reasons, always

be considerably less than these figures indicate; the principal one being the inevitable condensation in the cylinders. If, however, the various elements contributing to the reduction of the actual efficiency below its theoretically maximum amount be proportional to the work actually done in the steam engine, the form of this curve will still represent the relative efficiencies of engines working with the different steam pressures. From this we see that in advancing from 60 lbs. pressure to 150 lbs., we ought to increase the efficiency by 19%, or, what is the same thing, to effect an economy of 16%. The fact that an increase of economy is actually obtained considerably above this amount, when using the triple expansion engine, shows that this engine is working under conditions more nearly approaching to those required for the maximum efficiency than the other, and I think proves pretty conclusively that the reduction of the internal condensation by the lessening of the range of temperatures of the surfaces exposed to the steam has more than counterbalanced the loss due to the reduction of effect by the increased wiredrawing and unbalanced expansion incidental to the application of an extra cylinder, slide valve chest, etc. It is possible that a still further effect in this direction may be obtained by using four cylinders instead of three, but experience on this point is wanting at present.

The spot A in Figure 3, lying above the curve represents the height to which the efficiency has gone in starting from 60 lbs.; if 25% economy has been effected, while the spot B, still further above the curve, shows the similar height upon the assumption of an economy of 33%.

I have previously referred to the probability of our being able to use still higher pressures in the immediate future. Of advance in this direction I am not very hopeful for several reasons; but, in face of the advance recently made, it would be rash to be too positive. It must be remembered, however, that every addition to steam pressure increases the temperature of the steam. At 150 lbs. the temperature is 366° F., at 300 lbs. it is 422°. When it is remembered that the boiler plates which have to transmit the heat to the water must necessarily be hotter than the steam temperature, and that steel is considered to be unreliable when it is at what is called the blue heat, which commences at about 470° F., it will be evident that at a pressure of 300 lbs. there will be less than half the margin between the steam temperature, and the temperature of unreliability of the plates, that there is at a pressure of 150 lbs. per square inch, and only one-third of the margin there is at 80 lbs. pressure.

Further, an increase of steam temperature will probably be felt in the working of the engine itself, as there must be some limit of temperature at which the endurance of cast iron will cease, and we may be nearer that limit than we think. I believe that our friends the locomotive engineers found a limit of this kind in their cylinders at lower pressures than we are now working at, until they changed the method of casting them. There is the

further consideration that the higher pressures advance, the less margin there is to work upon in that direction, as is evidenced by the tendency to flatten itself, shown by the efficiency curve in Figure 3.

Turning now to the question of the boiler, I have stated that we are practically using the same design of steam generator as was common in 1871, but there are at present several attempts being made in the direction of economy in fuel.

As regards the production of large power upon the minimum of weight and space, where full economy is a secondary consideration, I have only to mention the wonderful performances of the boilers now being fitted in torpedo boats, to show that enormous progress has recently been made, but these boilers are necessarily unfit for ocean steaming purposes. The application of forced draught also, in the Royal Navy, to boilers of the ordinary type, with a somewhat similar object in view, has considerably augmented the power of our War Vessels, without adding greatly to their weight or cost, but here also economy of fuel is not the prime consideration. Forced draught has, however, been applied in merchant steamers with a view of lessening the dimensions of the boiler. This is rendered possible by the increased temperature of the fire being able to transmit more heat per unit of surface, and to render the boiler, surface for surface, more efficient than it would be if a lower fire temperature were used. It is evident that if the boiler surfaces are more efficient, less heat will be wasted up the funnel.

One of our energetic firms is at the present time fitting a vessel with boilers having an arrangement of forced draught with this idea in view, and has combined with it a very large extra amount of heating surface in a form of a tubulous boiler, called by the makers a low temperature boiler, with a view of still further extracting the heat which would otherwise escape up the funnel. This so-called low temperature boiler is really an advance in point of size, etc., upon a feed heating apparatus, satisfactorily fitted up by the same firm in several previous steamers.

Another question which forced draught has satisfactorily solved is the use of small and inferior coal. There is, at least, one British, and there are several Italian steamers now running, with very satisfactory results, burning nothing but very inferior coal, which could not possibly be burned with natural draught with the ordinary fire bars. By employing suitable bars, and closing in the ashpits, most perfect combustion is obtained, and it is claimed that even when comparing weight for weight of coal used there is a decided economy in this system, since there are no ashes left unconsumed, while, of course, considering the low price of dust coal as compared with ordinary steam coals, a large saving of cost is being effected.

When it is considered that on many stations and trade routes, where steamers have to obtain coal, even the best coals rapidly deteriorate, and that bad coal, besides involving

diminished power and reduced speed, means also a great waste of fuel from the incessant stirring and working of the fires, a system of forced draught may possibly prove to be useful and economical if applied to vessels in which it is important to maintain their speed.

I cannot conclude this Paper without a reference to what is deemed by some to be the fuel of the future. I refer, of course, to "Mineral Oil." Since 1856, and up to the present time, this fuel has been successfully used for marine purposes on the Caspian Sea, a region where oil is remarkably cheap and where coal is expensive. The local conditions are thus extremely favourable for the use of oil, and it is the question of cost which will ultimately settle the problem whether oil or coal is to be the fuel used in any region.

In every case in which oil has been successfully used up to the present time as a fuel for boilers, it is blown into the furnace and at the same time converted into a spray (or pulverized, as it is technically called) by means of a steam jet, this jet being obtained from the boiler itself. The amount of steam used for the purpose of pulverization has, I believe, never been definitely ascertained, but it is variously estimated at from 8 to 12 per cent. of the total production of steam in the boilers. Let us assume for a moment that it is 8 per cent., this will mean that for every 92 tons of water evaporated for use in the engine 8 tons of fresh water are lost, and must be supplied from the sea. If this is supplied from the main boilers, this will mean that a steamer exerting say 1,000 I.H.P. will require about 14 tons of sea water to be put into the boilers per day. What amount of scale this will produce I will leave others to calculate, but it is evident that such a system is wholly impracticable for extended ocean steaming. It is, of course, possible to use an auxiliary boiler working at a comparatively low pressure for the purpose of feeding the oil into the furnace, but this complication is not likely to be carried out.

When, however, the price of oil falls so low as to render it possible for it to compete with coal in ocean work, I do not doubt that it will be easy to find means to burn it, without employing *steam* to "pulverize" it. I believe the ultimate solution of the problem will be found in the use of compressed air, possibly of heated air, for the purpose of pulverization.

As soon as the question of transport from Baku to Batoum of the oil used for fuel has been satisfactorily settled, either by the laying of a pipe line or by greatly increased facilities of carriage on the Trans-Caucasian Railway, there can be no doubt that this fuel will come into general use for the purely local steamers, and possibly also for coasting steamers trading exclusively in the Mediterranean; but in view of the fact that such steamers will have to be fitted with a special system of bunkers, oil pipes, etc., and that the furnaces will require to be fitted with specially constructed fittings, all entirely different from those which are used when coal fuel is employed, it does not appear probable that

oil fuel will be used for ordinary steamers trading alternately between what may be called oil ports and coal ports, and it can only become general when oil depôts are established in every part of the Maritime world.

I have in this Paper attempted, however imperfectly, to scan the prominent features of the progress in Marine Engineering which has lately taken place, and to bring into notice the attempts which are at the present time being made to obtain a further advance. I have indicated that, in my opinion, the next step forward will probably be other than in the engine proper, but I submit my views on this point with great deference, as with engineering progress it is always wise "not to prophesy unless you know."

DISCUSSION.

Mr. A. C. Kirk (Member of Council): My Lord and Gentlemen, as my firm has come somewhat prominently forward in this Paper I take the liberty of addressing to you a few words. All through the present meetings I think the style of papers we have had has been extremely appropriate to this the largest shipping port in the country. One paper called the attention of our shipowners to a trade of importance; another paper has shown the causes of losses at sea; losses, whoever they fall upon, whether the shipowner or the underwriter, are a loss to the country, and this Paper records the steps that have been taken within the last half-dozen years to render our steamships more efficient and more able to compete in the competitive war of the world than their predecessors were. I hope the result of all will be that in this very important centre of shipping some good may come out and that our shipowners may be restored in the end to the prosperity to which they have been so long entitled by the spirited and adventurous way in which they have pushed their business. The history of the triple expansion engine shows amongst other things the important part that the shipowner himself can play in the advancement of the more mechanical parts of his business, although these are parts to which he may perhaps profess no very special or technical knowledge. When the engines of the "Propontis" were built, your very enterprising citizen, Mr. W. H. Dixon (I do not know whether he is in the room or not), was fully convinced, some 14 or 15 years ago, of the necessity of taking some further step to improve the economy of steamships. He was also fully persuaded that this was to be done by increasing the pressure of the steam. At that time there was a feeling of shyness in adopting pressures much above what was then in use with boilers of the ordinary type, and this was to some extent justified, because the manufacture of steel was nowhere, and the manufacture of iron was not capable of competing in the way steel does now with thick plates, nor had we the tools, the experience, or confidence in handling them, which we have now. Under these conditions Mr. Dixon resolved to give the late Mr. Rowan's water-tube boilers a trial. There was not the smallest doubt that these boilers were abundantly strong and had sufficient heating surface, neither were they deficient in circulation, and it was his adopting these boilers that really brought up before me the question of the triple expansion engine, because it fell on myself to propose an engine capable of utilising efficiently the high pressure steam that would thus be got. I said at once that our present compound engine as the pressure was raised would fast drift into the condition of the single expansion engine which it had superseded. The rate of expansion in each cylinder was already quite as much as it ought to be with the pressure

of 60 lbs., which was then usual. Now I said to myself, when we go to a higher pressure (150 lbs.) with this boiler you will simply lapse into a couple of ordinary engines. Such was the simple argument in my mind at that time. Mr. Dixon accordingly approved of the engines being made triple expansion when the matter was laid before him. They were so made, and as Mr. Parker tells the rest of the story I need not further allude to it. But there is one thing I would mention. The Board of Trade of those days, when the engines were finished, ordered the ship to go on a three-days cruise to test the boilers, which was a most sensible and liberal procedure, and Mr. Parker was one of the surveyors appointed—there were several of them, and a very jolly time we had. The boilers were thoroughly tested, and I think we all enjoyed ourselves very much. So you see Mr. Parker's acquaintance with the triple expansion engine dates from a very early period indeed—from this its first trial, in fact.

Now as to the question how far we are to go in pressure, it is not for me to say. But we have to recollect this, that every successive step upwards we take in pressure, we make a smaller step in economy. It is very unfortunate, but the temperature of steam does not rise in proportion to the pressure. Therefore some of these days there must come a stop to this increase of pressure, not but what you will get continual economy as you go up in pressure, but at each step that economy will be smaller and smaller, while the cost of the machinery will increase, and we have not only to look at the mechanical reasons, but we have also to look at the commercial ones. With regard to the quadruple expansion which has been referred to, it has been tried by my friend Mr. Brock of Dumbarton. I do not know the result, but I know that some economy has been effected, not perhaps very much, with a pressure of 160 lbs.—a comparatively low pressure to which to apply quadruple expansion. It is the boiler after all that bars immediate progress. The only part of the boiler that does bar immediate progress is the furnace, because as to the rest of the boiler, the boiler shell, the tubes, and the stays, we can get over all difficulties, but the furnace is the weakest part of the boiler, and anything further that can be done in the direction of a simple and strong furnace would be a very great benefit.

That is all the more important perhaps because with the higher pressures the scale deposited on the boiler is harder than it is when the pressure is lower. I almost incline to think it shows a disposition to deposit more upon the furnace than it used to do. This brings me to another point. There is no doubt about it, we must set our faces fairly to keep scale out of boilers altogether, at least to have the amount perfectly under command. I think there is no doubt about that. I am happy to say I am not talking about a thing that is impracticable or an enthusiastic idea, but it has been already accomplished. I do not say to any great extent, but it has been done, and that too without very much sacrifice of coal. Messrs. Weir have shown one way of doing it, with but little loss, but there is no doubt there is a wide field here for progress.

There is one thing that has helped the triple expansion engine to some extent, perhaps—it has lent itself to the application of some smaller economies of which in the ordinary compound engine we might, perhaps, vulgarly say the game was not worth the candle. As an illustration I refer to Messrs. Francis' feed heater which is quite worth applying in a triple expansion engine. Then there are other little sources of loss which when you multiply them by three cylinders, ought to be more closely attended to than when there are only one or two to deal with. I am afraid, gentlemen, I have exhausted your patience, and I would just close with a very brief remark on the diagrams before us. These would appear to me to be trial trip diagrams, no doubt representing 25 or 30 per cent. more horse power than the engines are intended to work at regularly. Now under these conditions the diagrams of Fig. 1 (Plate XI.) would give too great a range of expansion when the engines are working regularly at sea, while the diagrams of Fig. 2 approach much more nearly what would be an economical degree of expansion. There is this to be recollected, that as you increase the number of

successive expansions in separate cylinders in a steam engine it becomes a less flexible machine. To work to advantage it has to be made to work at a definite power and not too much varied from that power either above or below. If you work it at too low a power you have too much cooling surface in your cylinders—too much friction in proportion to the power, and altogether the efficiency is found to fall off. Therefore, gentlemen, I think Mr. Parker's remarks as to these diagrams are scarcely justified, or, at least, perhaps, he will be so good as to explain them a little further. I confess I do not follow Fig. 3, and, perhaps, Mr. Parker will kindly explain that a little further also.

Captain Watt (Visitor): My Lord, I should like to ask, if Mr. Parker is going to reply, whether he considers the difficulty of the collapsing of the furnaces in these triple expansion engines has been got over, because, the difficulty, I believe, lies, as Mr. Kirk has said, in the furnace. He has not said that it lay in the collapsing of the furnace, but within my own knowledge—I am now speaking as a shipowner and not as a sailor—I have known a great many of them collapse, and there has been a great deal of trouble with them; and when Mr. Parker comes to reply, if he does, I shall be very much obliged if he will say whether he considers that difficulty has been got over.

Mr. J. Fortescue Flannery (Member): There is one point which I rather regret Mr. Kirk, who was the pioneer practically of this class of engine, did not allude to, because it is one of the most practical and embarrassing points connected with this subject at this moment, and that is, the best mode of changing the existing compound engines into triple expansion engines. Mr. Parker has described, in his Paper, three modes of doing this, and no doubt the adoption of either of those modes, or of none of them, will depend largely upon the design and size of the engine to be treated; but I think that in the ordinary engines of the Cargo Mercantile Marine, which vary from about 600 I.H.P. to 1,500 I.H.P., the alteration would not generally be effected in any of the ways that his Paper has described. If we turn back for a couple of years to the history of the triple expansion engine, we find that on the north-east coast these engines were first brought out—it is the small engines I am referring to—on the two-crank system, with tandem cylinders acting on one of the cranks. It has been found in practice that that class of engine did not work so well as the three-crank engine; and in the result on the north-east coast, and also here in Liverpool, where a good many of that class of engines are being made at the present time, the three-crank engine is being almost universally used in place of the two-crank engine. Now, if we turn from that to the question of altering the existing compound engines, and remember that the triple action of engines depends for its economy upon very high pressure, which means that you must renew the boilers of existing ships, and open up the decks to get in new boilers, you will see the comparative expense which could be saved by utilising the framework and some of the working parts of the old engine is very small indeed. You must have new cylinders in whichever form you take them, and all you save is the framework and some of the working parts. The comparative expense of those is very slight when you are dealing with the whole matter, and you have an engine, if you adopt that patchwork system, which is proved by experience to be less efficient in triple work than the three-crank engine. I think, therefore, experience will show—and it will be only a few years hence, I believe, before the whole of our mercantile fleet will be changed—that in the practical changes which will take place, we will not adopt any one of these systems, but will make a clean sweep of the engine-room and put in entirely new engines. I daresay Mr. Parker, and probably also Mr. Kirk, have considered these points, because they are of very great practical importance to the shipowners of this city and elsewhere.

Mr. Charles Marvin (Visitor): My Lord and Gentlemen, I had no intention of speaking this

morning upon Mr. Parker's Paper, but a suggestion has been made to me that I should say one or two words with regard to a matter to which he has alluded in his very able and instructive Paper. It is only sixteen years ago since Russia began to use liquid fuel in the Caspian Sea. It is only eight years ago since liquid fuel came fairly into play, yet at the present moment in the Caspian Sea there are 200 steamers burning it exclusively. On the River Volga there are about 300 other steamers, and I think I may say that liquid fuel is used upon one-sixth of the total mileage of the railways of Russia, in addition to which it is employed by about 1,000 stationary engines and locomotives in various parts of the Empire. Now, if one were to draw a line from Batoum on the Black Sea across to Merv, to which point the Russians have just completed their railway, a distance of over 1,000 miles, and due north from those two points to Moscow, a distance of about 1,500 miles, the area enclosed within the triangle would represent the liquid fuel region of Russia. More recently liquid fuel has come into use on the Black Sea on board the steamers running between Odessa and Batoum, and I have every reason to believe that as this liquid fuel becomes cheaper in the Black Sea and petroleum deposits in the East become opened up, liquid fuel will come into play more and more in the region stretching between the Euxine and the China Sea. I should say that besides the resources of liquid fuel at Batoum there are also available the very considerable petroleum deposits of Egypt, the Persian Gulf and the Burmese Coast, and again in China and Japan, forming a complete series of links from the Mediterranean to the China Seas. In this country the use of liquid fuel has not made very much progress, for the simple reason that the conditions are different here to what they are in Russia. In this country liquid fuel has to compete with coal selling at six shillings or so a ton, whereas in the Caspian Sea the price of coal until recently was about £6 a ton. Moreover, when the use of liquid fuel was proposed some twenty years ago in this country the supply of waste oil was very limited, and the moment a demand arose for it a price was put on which was practically prohibitory. More recently the development of the paraffin industry of Scotland has brought into the market very considerable quantities of this waste oil, and I was assured in Edinburgh a few days ago that many million gallons could be obtained and transported to different parts of England at the rate of about a penny a gallon. Before sitting down I would venture to make one remark with reference to a suggestion of Mr. Parker's, that instead of steam, compressed air will very probably come into play. At Edinburgh I took part in some experiments with the Lucigen Light, which is a kind of flare produced by pulverising liquid fuel by compressed air, but the noise arising from the rush of compressed air was so great as to resemble a steam roarer, and the workmen employed at the Forth Bridge told me that when this compressed air was used in the riveting furnaces, and in illuminating the works, they found the noise very distressing indeed. No such noise prevails on board the Caspian steamers, and unless some means can be adopted for lessening it I do not think that it could compete very favourably with steam. There is one other point which I would refer to. During the reading of Mr. Martell's Paper the other day I heard some one say close to me that liquid fuel emits a "confounded smoke." As a matter of fact liquid fuel as used in Russia is a smokeless fuel. There is no smoke whatever issuing from the funnels of the steamers and locomotives using it. On this account it has one very great advantage over coal, and I need only cite one illustration—its employment on underground railways—to show how very superior it would be to coal in this respect.

Mr. John Scott (Member): My Lord, I would venture to offer a few remarks in furtherance of this discussion, as being one probably of the few remaining engineers now alive who had something to do with the introduction of the compound engine at sea in 1858. I may mention, although it is probably known to some of my friends in this room, that when the vessel to which I especially refer, the

"Thetis," was started in that year and run for some time between the Clyde and Liverpool, what has been talked of as the initial pressure of the compound engine was not then 60 lbs. in that ship but 125. The boiler then used was one of the types referred to in Mr. Parker's Paper, being that of the Rowan or Braddock type of boiler. I believe the efficiency obtained from that engine in 1858 has not yet been surpassed by any of the more modern engines which have since been produced, but I believe that that efficiency was obtained not from the type of the engine or manner in which the steam was used in the engine, but was principally due to the boiler. That boiler failed not from mechanical but from chemical reasons, and probably, and in this I quite agree with Mr. Parker in his expression of opinion, that type of boiler will not be revived, but I think that the lessons which were taught should not be forgotten, and that we have to look very largely to the efficiency of the boiler which we shall now determine to use if we are to proceed in the direction of obtaining the additional advantages of economy which springs from the triple expansion system. A gentleman on my left has referred to the trouble of the construction of modern boilers by the use of the high pressure system from difficulty arising in the furnaces. Now we all know, so far as mechanical tests are concerned, a furnace has been produced—well known as the corrugated furnace—which can stand all the mechanical tests which are necessary for producing a strong furnace, able to carry 250 or 300 lbs., if you choose to use it, but there are difficulties arising from the actual management and work in the steam engine which may probably render even so strong a boiler as that difficult in practice to work, because there is no doubt that matters from the lubrication of the engine are introduced into the boiler which, unless they are periodically removed, may cause trouble, as was referred to by a gentleman who spoke a little while ago. He has called on Mr. Parker to reveal probably some of the secrets of his Association, as regards the collapsing of furnaces, and I should like to know whether the collapsing which has been referred to has occurred from the deposit of extraneous matter on the furnace area, or from any weakness inherent in the furnaces themselves. A point has been referred to in Mr. Parker's Paper, which I have only read since I came into the room, as to one of my brother engineers being at present engaged in adding to the heating surface of his boiler by the introduction of what I think is called a tubulous arrangement in the chimney, I fancy for utilising the surplus heat which may pass off by that exit. It is a very curious thing, when the "Thetis" was used with steam at 125 lbs. pressure in 1858, an apparatus of this description was fitted round the funnel with a view of utilising the surplus heat and raising steam at a low pressure to be condensed for the sake of making up the fresh water necessary for working the tubulous system of boiler. That apparatus failed, not because it was a bad apparatus, but because there was not sufficient surplus heat to boil the water. I think now in the days of forced draught when there is probably a considerable amount of surplus heat passing up the chimney, an apparatus of this kind might be revived with considerable advantage, because, possibly with an apparatus which might be easily cleaned, salt water might be used and the products of the salt water passed into the main boiler with a view of keeping it clean. With regard to the question of forced draught referred to in the Paper, I think that the use of forced draught may become more common in the merchant service, not possibly from the amount of economy to be directly obtained from its use, but because in long voyages the use of forced draught undoubtedly tended to keep the internal surface of the boiler clean from the rapid passage of the air, and to prevent the deposit of sooty matter which acts so deleteriously in the transmission of the proper heat of the coal to the boiler surface. I am quite aware that forced draught has already been used in very long voyages by one firm, at any rate, in this City, and I have been led to believe that one of the principal advantages obtained from its use is the one which I have indicated—the keeping the surface clean. If any moderate amount of draught is used in that way, I believe it would be extremely valuable, and I hope to see its use very much extended.

Mr. A. E. Seaton (Member) : My Lord and Gentlemen. One of the points of great importance, and one that has not been touched on by Mr. Parker directly, in his Paper, but which was incidentally raised by Mr. Flannery, is the efficiency of the triple expansion three-crank engine, as compared with the ordinary engine. I have just lately received some information upon the relative merits of the two-crank triple expansion engine as against the three-crank, very valuable from that point of view. It will be remembered, perhaps, that in a Paper read by me some eighteen months ago before this Institution, I spoke of two ships, named the "Electro" and the "Dynamo," that we had built a few months previously. The one had a three-crank engine and the other a two-crank engine, both being triple; the ships were exactly alike; the boilers and propellers were exactly alike, and both ships were engaged in the same trade. These two ships were engined in that particular way in order to demonstrate that the three-crank was better than the two, and to try and find out which of the two systems was really the more economical. In my Paper I gave some of the results deduced from indicator diagrams taken on the trial trip. I did not at that time attach very much importance to the information I then gave, and, therefore, dwelt very lightly upon it. These ships have now been running for a little over two years. The superintendent engineer of the Wilson Line gave me last week the result of their performances, and it amounts to this, that the consumption of coal per I.H.P. is precisely the same, that he can find no difference, but that the three-crank engine drives its ship half a knot or 5 per cent. faster than the two-crank engine. I think that is a very important point, and one which has not been sufficiently dwelt on by marine engineers, because, in discussing the relative merits of the two and the three-crank engine, it has been practically limited to comparing the consumption of coal per I.H.P. Shipowners do not care so much about that as the consumption of coal per ton carried, and the speed at which it is carried; and, therefore, I venture to give this information to-day to this Institution. I do not think that we have far to look for the cause of this. I take it that the uniformity of motion of the propeller gives this very much better result, together with, I think, the possibly, and I may say the probably small friction of the journals, guides, &c., &c., in the three-crank engine. The same result has been observed by us in other ships, but in no case except this have we had two ships exactly alike to compare. There is no question now—at least in my mind, that the three-crank engine is superior in every way to the two-crank one, whether it be a quadruple or a triple expansion, because, whether you have the quadruple engine, or the three-cylinder triple, you have the inherent defects of the two-crank engine. The superior propelling effect due to uniformity of motion was observed by me some years ago in the case of some ships fitted by us with single-crank engines having a heavy fly-wheel, as compared with sister ships fitted with the two-crank engine and no fly-wheel. It was not a question then so much of the consumption of coal between the two, for we did not trouble about that; as a matter of fact, the consumption of coal per I.H.P. was very little different in the one than the other, but we did observe that the single-crank ships made better voyages in the winter time than the two-crank ships, and on questioning the engineers we found it had to be very bad weather indeed when they were compelled to slow down the fly-wheel engines; in other words, they could keep them moving at full speed when the two-crank engine had to be slowed down on account of heavy racing. Then, again, as to the fly-wheel, the power stored up during the time that the propeller was out of the water would be stored in the fly-wheel, and given out by it again on immersion. The question of furnaces has been raised, and I was rather surprised to hear that, because I thought the question of the strength of the furnaces was disposed of some years ago. I thought that Mr. Fox's invention of the corrugated furnace dispelled the difficulty altogether. However, a gentleman has raised it to-day, and he seems to think that there is some danger of collapse with these high pressures, but so far, my experience is that there are fewer cases of collapse since we used the higher

pressures than in the old days with comparatively low pressures. The corrugated furnace, as I have said, has gained the confidence both of sea-going and manufacturing engineers, and I never heard from one or the other any doubt expressed as to its perfect safety. As regards the cleanliness, that is another matter. I quite agree with what Mr. Kirk says, that the tendency to put on scale in these furnaces with the higher pressures seems to be greater than with the old furnaces and lower pressure. At the same time it only requires on the part of the engineer a little more care to keep the furnace practically free from scale. In fact, in one set of boilers turned out some little time ago, the chief fault to be found was that no scale at all was put on. The question of using clean feed water will have to be dealt with sooner or later. I am not prepared to point just now to any better way of doing it, but so far the necessity for using clean feed water has not been shown to be so urgent that any shipowner would care to go to the expense of either carrying fresh water in the double bottom or the tanks of the ship, or of providing distilling boilers.

Mr. A. Blechynden (Member) :—Before Mr. Parker replies I should like to correct at least one or two statements which have been made. They are to be found in the third paragraph of page 127. It is stated that the first compound engines on the three-cylinder plan were built for the "Propontis," and that the second were built for the "Isa." Now in the Ouseburn Engine Works at Newcastle-on-Tyne, there were three cylinder compound engines begun in 1873. They were to have been completed for sea early in 1874, and were, in fact, completed ready for putting into the ship in 1874 in one of the earlier months, February or March; but owing to the failure of the firm to whose order the engine was built, they were not put into the ship and tried until the latter end of the year. The trial trip date was the 19th of September, 1874. They were fitted into the "Sexta," built by Messrs. Gray of Hartlepool. The size of the engines was cylinders 11 ins., 17 ins., 24 ins. diameter by 18 ins. stroke, and 120 ins. pressure. These engines did very well, burning something like $1\frac{3}{10}$ lbs. of coal per I.H.P.

Mr. W. Parker (Member of Council) :—My Lord, I shall be as brief as possible in replying shortly to the several speakers, because as your Lordship has pointed out, the time at our disposal before we join the steamer that is to take us to the "Germanic" is very short. Mr. Kirk has referred to the work that was done by the "Propontis" on the occasion of her trial trip, at which I had the pleasure of being present along with Mr. Kirk, Mr. Brock and other gentlemen. That trip, as Mr. Kirk has explained, was a very enjoyable one, but it was also productive of substantial gain to our engineering knowledge. The data obtained at that trial, when tabulated and properly analysed, convinced us, I think, that if boiler pressures were to increase, the ordinary compound engine must give place to one that would utilize high steam pressure by dropping the temperature in three steps. I think that great credit is due to the owner of the "Propontis," Mr. W. H. Dixon, of this City, who gave Messrs. Elder the order for the engines with which we were thus able to experiment. But there is another gentleman who is deserving of even greater praise, and that is Mr. Cornelius Thompson, of Messrs. George Thompson and Co., London. When making a departure from sailing ships to steamers he consulted Mr. Kirk and myself as to whether he would be justified in adopting this description of engine in which he understood we had confidence. In face of the opinions of a great number of his shipowning and engineering friends, who advised him against venturing upon any such novelty which had already failed, and which, it was contended, could not possibly be so economical as represented, Mr. Thompson had the courage to order a large vessel of 3,600 tons and to have her fitted with triple expansion engines of 2,000 I.H.P.; and to his action more than to that of any other man in the kingdom are we indebted for

the benefits accruing in the shape of economy of fuel, &c., from the use of this description of engine in the one hundred and fifty steamers now running with it. Mr. Kirk has referred to the furnaces, which he said he believed to be the weakest part of high pressure boilers. I beg to differ with him there. I think there are other parts of the boilers much weaker. When these high pressures were introduced the plain furnaces we were then using were certainly very weak, but thanks to Mr. Samson Fox we have now a furnace that can withstand the high pressure we are using. I have no hesitation in saying that if it had not been for the energy and perseverance of Mr. Fox in experimenting and overcoming the difficulties he had before him when he was commencing the manufacture of corrugated furnaces, and in conjunction with that the introduction of steel, which admitted of a stronger material being used for the shells of the boilers, we should still have been working at 70 or 80 lbs. pressure, and shipowners would not have had the substantial benefits afforded by the triple expansion engine. Mr. Watt made reference to furnaces collapsing, and Mr. John Scott asked whether the collapsing of corrugated furnaces was due to their weakness as furnaces or to any other cause. Well, a great many furnaces have collapsed, and undoubtedly more of them in the case of triple expansion engines than with ordinary compound engines. Why that should be I have never properly understood, although I took great care to personally examine, I may say, almost every one of the boilers where collapse occurred with corrugated furnaces during the first three or four years after such furnaces were introduced. A good deal has been said in shipping circles here about the failure or supposed failure of the boilers fitted in the large Mexican steamers which were engaged running from this port. I came down specially to Liverpool and examined those boilers when the vessels arrived. A report went forth that the collapse was due to the high pressure which was necessary with triple expansion engines, and which the furnaces were too weak to withstand. I can assure you, however, that the collapsing of those furnaces was simply due to gross neglect or carelessness. The engineers allowed the corrugation in the furnaces to become solid with lime and scale. I have in my office at the present moment pieces of this scale exactly the form of the corrugations three to four inches thick. Anyone can see them there and satisfy himself that no such thing as structural weakness was the cause of the collapsing. Mr. Seaton, I think, said there was more lime found upon corrugated than upon plain furnaces, why he could not tell; and also that he has seen many collapsed furnaces that have had no lime on them at all, and from the appearance of which it was impossible to tell why they had come down. This matter has already been discussed at some length before the Institution, and I will only now repeat what was said on a previous occasion, namely, that in some cases we were able to trace the cause of collapse to the deposit from the oil used in the cylinders. This deposit was proved to be a bad conductor of heat, and when it got lodged on the furnace crowns the plates became red hot and collapsed. That may account for some of Mr. Seaton's cases of collapse. Mr. Kirk inquired respecting the diagrams, and especially Fig. 2. I think he said that as these were trial trip diagrams they did not give really the work the vessel would be doing at sea, and that an engine might be so constructed that it would work economically at sea irrespective of its work on a trial trip. In the case of the engines Fig. 2, I find that when working at sea they indicate only 64 per cent. of their trial trip power, and it will be seen on looking at the low pressure card that the steam is exhausted into the condenser considerably above the atmosphere, which is far from satisfactory. Engines (Fig. 1) when working at sea indicate 92 per cent. of their trial trip power and exhaust into the condenser considerably below the atmospheric line. Engines (Fig. 2), although showing a very large power, were therefore really being worked at that power most extravagantly. My object in illustrating the work done by these engines is to show how easily the uninitiated can be deceived, unless the work done as shown on the diagrams is taken into consideration. Now I think we should ask ourselves whether it is good engineering practice to make such a difference

between the power obtained on the trial trip and that obtained in the ordinary working at sea. With regard to the Fig. 3., I may explain that the ideal line of efficiency as it is called is obtained as described in this paper by taking the absolute temperature of the boiler pressure minus the temperature of the condenser, which is called 100, and dividing that by the absolute temperature of the boiler pressure, which gives a point as seen, at 50 lbs. pressure, and again other points at 100, 150, and up to 300 lbs. pressure. But when we put the spots A and B on the diagram, A representing 25 per cent. of economy that is really being obtained by the triple expansion engine over the compound engine, and B representing similarly 33 per cent., we find that the actual gain in efficiency by increasing the stages of expansion is greater than the theoretical gain, because the work of expansion is more perfectly performed or the loss from condensation is less. That is what I have endeavoured to show by that curve. Mr. Flannery raised the question as to whether it would be advisable to make the engine with three or with two cranks, and I think he stated that I had omitted to refer to the three crank engine. I think Mr. Flannery has not read the paper quite correctly. If he turns to page 133, paragraph two, he will find the following words "This conversion may be made in at least three different ways; first by adding another cylinder and crank, necessitating an addition to the bed plate and, therefore, also to the length of the engine room." Here I point out that three cranks can be used. At the same time I can well agree with what Mr. Flannery and Mr. Seaton have said with regard to the three crank engine working more uniformly if the steam is properly distributed, and if the cuts off and all that is necessary be so arranged that the engine can work on uniform equality. Some five or six years ago I took out three sets of diagrams to clear up this question. One set was from the three crank engines of the "Iberia," another set was taken from the two crank engines of the White Star steamer "Britannic," and a third set was taken from the "City of Berlin's" engines. From these diagrams torsional diagrams were constructed to show the twisting moments on the crank shafts, and it was found that the three cylinder engine had a greater twisting moment on its shaft than either of the other two cylinder engines. I mention this to show that because an engine has three cranks, *it does not necessarily follow*, as some people think, that it must work more evenly and uniformly than it is possible for an engine to do with two cranks. I am sorry that time has not admitted of this discussion lasting longer, and that Mr. E. A. Cowper has not given us the benefit of his views. Every one knows that Mr. Cowper was one of the first to introduce high pressures, and that some twenty years ago he did very great work in that direction. I should therefore have been very glad if we could have had the advantage of his observations on this subject. I was not aware until Mr. Blechynden told us to-day that the engines he refers to of 11 ins., 17 ins., and 24 ins., were made in 1874. I do not remember ever having heard of the ship he mentioned. I am sure if she had been a classed vessel she would have come under my notice. In conclusion, my Lord and gentlemen, I have to thank you very much for the patient hearing you have given my Paper. My only object in preparing it was to bring out clearly the position we stand in at present, and to suggest in which direction we should look in the immediate future for further improvement.

The President:—Gentlemen, I am sure you will wish me heartily to thank Mr. Parker for his very able and instructive paper.

ATLANTIC STEAMERS.

William John, Esq., Member of Council.

[Read at the Twenty-seventh Session of the Institution of Naval Architects at Liverpool, July 29th, 1886; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

When I was asked to read a Paper at these meetings I felt it to be a high compliment, and consented to do so, but when later on I agreed that the Paper should be on Atlantic Passenger Steamers, I did not realise quite what I was undertaking. In Liverpool of all places in the world the subject of Atlantic Steamers, of all sizes, types, and speeds, from the great passenger liners downwards, has been discussed in all its bearings, commercial, practical, scientific, historic and prophetic, and it is hopeless to attempt to say anything new on it here. One thing, however, I may hope to do, and that is to bring before you impartially, certain facts which may be of interest, and which when recorded in the pages of our Transactions may be found of some use as data for future reference. I also hope, and I am sure the Council of our Institution hope we may be favoured with a full discussion of this subject and that we may hear the views of some of the many Liverpool gentlemen interested and engaged in the Atlantic Passenger trade, who know far more about it than I do, and whose opinions will necessarily carry more weight.

In dealing with passenger steamers I want to do so principally from a shipbuilder's point of view; but as you will easily see it is impossible to lay down any hard and fast rule for my guidance in the matter, for the moment I commence to think over Atlantic Passenger ships as a shipbuilder I am met by the question whether the present tendency towards divorcing the passenger and cargo trades from each other is likely to continue or not. If the answer is,—yes! then it seems to become an important question, for the present at least, how to build on moderately small dimensions the fastest, safest, and most economical passenger steamer, using all the most modern improvements to make her commodious and luxurious and an easy sea boat into the bargain.

If cargo is still to be carried in passenger ships a moderate speed only will be aimed at in the immediate future, while every effort will of course also be devoted to economy of fuel, comfort and safety, and to giving a fair carrying capacity.

This latter policy is one which may possibly prevail, at least for a time, as it has powerful supporters here in Liverpool, but I cannot help thinking that very high speeds,

higher than we have yet attained, must eventually gain the day. I also think we are on the eve of important movements that will indicate what the next step in the Atlantic passenger trade is to be; for it must be remembered, among other things, that none of our present English Liners, even the latest, have yet been fitted with the most modern improvements for economy of fuel or for quick combustion, such as triple expansion engines or forced draught. They—our Liners—must therefore be at some disadvantage, other things being equal compared with the ships of the future and the Foreign ships already possessing them.

In saying this I am of course by no means speaking or thinking disparagingly of the magnificent ships that are now sailing from Liverpool, and which are so well known to all here, for no one admires them and their performances more than I do. But there can be no finality in such matters, and if we are to hold our own present undoubted supremacy in the Atlantic trade against the heavily subsidised French and German steamers, embodying as some of them do, these later improvements, we must march forward or else we shall bring even more formidable rivals into the field,—I mean: from the other side of the Atlantic.

Forward we must go, and shipowners and shipbuilders must work together for the common end, the former studying and specifying the conditions of the trade, and the latter studying to fulfil them to the utmost possible extent.

And this reminds me that the first sight I remember to have had of what might then perhaps have been called an Atlantic Passenger Steamer was one of the most striking and impressive sights I have ever seen. It was the "Great Eastern" which you have now here in the river, differently employed, steaming up Milford Haven about 25 years ago between two lines of the Channel Fleet of old two and three decked wooden line-of-battle ships the whole fleet saluting with yards manned. It was a sight to be remembered and one which certainly enhanced the charm I felt in the study of Naval Architecture. More than this, that ship, with all her mournful career, has been a useful lesson and a useful warning to all Naval Architects who seriously study their profession. A lesson of what can be done in the safe construction of huge floating structures, and a warning that the highest flights of constructive genius may prove abortive if not strictly subordinated to the practical conditions and commercial requirements of the times. This is the most notable example since the time of Archimedes and the Egyptian Ptolemys some 2,000 years ago of the greatest floating structures of the age being produced by some of the most famous mechanical men of the age without any prospect of their becoming practically or commercially useful.

How different has been the growth of the Atlantic passenger trade, where the shipowners and merchants have joined hands with the shipbuilders and engineers, to make the ship suit the requirements of the trade, as near as may be. After mentioning the "Great Eastern" incidentally, one naturally turns to the "Great Western" as perhaps the pioneer of steam in the Atlantic trade; and when we remember the "Great Western" and the "Great

Britain,"—the early days in which they were built, and the enterprise that gave rise to them, it seems astonishing that Bristol by want of attention to her River and her Docks missed the opportunity that seemed to be opening out for her. What Bristol missed, and what the United States struggled hard for, Liverpool seized with a grip that has never relaxed, and is not now likely to relax without a desperate struggle,—whatever direction the opposition may come from.

The "Sirius" and "Great Western" crossed the Atlantic in 1838, and in 1840 the first ship of the since celebrated Cunard Company made her first voyage. This was the "Britannia," which, with her sister ships the "Arcadia," Caledonia," and "Columbia," kept up the Mail Service regularly at a speed of about 8½ knots an hour.

The "Britannia" was 207 feet in length between perpendiculars, and 34 feet 4 inches extreme breadth, 22 feet 6 inches depth of hold, 423 horse-power (nominal), and 1,156 tons burthen,—built of wood and propelled by paddles.

I mention this as the starting point of the Atlantic Passenger Steamers. I need not attempt to trace the growth of the Cunard, the Inman, and the other great Liverpool Lines, for they are all described fully and eloquently in the fourth volume of the late Mr. Linday's admirable work on the "History of Merchant Shipping and Ancient Commerce." I need only pick out a point of departure here and there for the sake of continuity.

In 1850 the Collins Line started in opposition to the Cunard, and it, after a series of disasters, collapsed in 1858. This was three years after the "Persia," the first Cunarder *built of iron*, had been completed.

In 1850, also, the Inman Line was started, with the "City of Glasgow," of 1,600 tons B.M. and 350 H.P. She was built of iron, and was the first screw steamer sent across the Atlantic from Liverpool with Passengers, and was the pioneer of the great emigrant trade which Mr. Inman above all others did so much to develop, and to make cheap and comfortable for the emigrants themselves, as well as profitable to his Company.

That the builders of the celebrated old "Great Britain" in 1843, and Mr. Inman in 1850, should have pronounced so decisively in favour of the screw propeller in preference to the paddle for ocean steaming is a proof of their true practical judgment,—a proof which time and practical experience have made abundantly clear.

While the Cunard Company went on developing their fleet, from the early wood paddle steamer "Britannia," of 1,130 tons in 1840, to the iron paddle steamers "Persia," &c., in 1858, the iron screw steamer "China" of 1862, to the still more important screw steamers "Bothnia" and "Scythia,"—vessels of 4,335 tons, in 1874; the Inman and other lines were as rapidly developing in speed and size, if not in numbers.

The year 1874 is memorable:—for it saw the White Star steamers "Britannic" and

"Germanic" put into the water, as well as the Inman steamer "City of Berlin" and the two before-mentioned Cunard steamers "Bothnia" and "Scythia." By the addition of these two ships to their fleet—the White Star Line, although started only in 1870, reached a front rank position in the New York Passenger Trade.

I have given, in separate tables, the logs of several of these ships,—some from published documents, and some kindly furnished me by the owners, and I need only briefly summarise them here.

The "Great Western" had crossed the Atlantic from Bristol to New York in 15 days as early as 1838. The first Cunard steamer, the "Britannia," was about the same speed, *i.e.*, from $8\frac{1}{4}$ to $8\frac{1}{2}$ knots an hour. The average duration of the Cunard voyages in the year 1856 was 12·67 days from Liverpool to New York, and 11·03 days from New York to Liverpool.

The "Bothnia," in 1874, reduced the passage to about 9 days. The White Star "Britannic," in 1876, averaged 7 days 18 hours 26 minutes outwards from Queenstown to New York, and 9 days 6 hours 44 minutes homewards, and has averaged, for the last 10 years, 8 days 9 hours 36 minutes outwards, and 8 days 1 hour 48 minutes homewards. The "City of Berlin,"—of the Inman Line, also built in 1874, averaged 8 days 10 hours 56 minutes outwards, and homewards 8 days 2 hours 37 minutes; and for the 9 years from 1875 to 1883 inclusive, averaged outwards, 8 days 19 hours 56 minutes, and inwards 8 days 8 hours 34 minutes; or,—putting it into rounder figures,—the "Britannic" had reduced the average passage between the two points to $8\frac{1}{4}$ days, and the "City of Berlin" to $8\frac{1}{2}$ days.

From the year 1874 on to 1879 no further advance was made in Atlantic Steaming; but in that year the "Arizona" was added to the Guion Line,—and it soon became evident that another important stride had been made in the Atlantic Passenger Trade, which would lead to most important results. The results, as we all know, have been sufficiently startling.

The Guion Line, which had started in 1866 with the "Manhattan," had now the fastest passenger ship on the Atlantic. In spite of burning some 50 per cent. more coal than the "Britannic," the ship was an obvious commercial success. The spirited policy which brought her into existence was appreciated by the public, and the other lines had to move forward.

Then followed a period of rivalry, the Cunard Company building the "Gallia" and "Servia," the Inman Company the "City of Rome," and the Guion Line the "Alaska," all of which were completed in 1881. After them came the "Oregon" for the Guion Line (1883), the "Aurania" the same year for the Cunard Company, and, later still, the "America" for the National Line, and the "Umbria" and "Etruria" for the Cunard Company in 1885.

Since the completion of the "Etruria," for various reasons there has been a pause in the tremendous strides made since 1879, and we may here briefly review the results. Taking the "Britannic" as a standard, with her 10 years average of $8\frac{1}{4}$ days across, and her quickest passage of 7 days 10 hours 53 minutes, we have now the following steamers of higher speeds.

Taking them in the order of their absolutely fastest passage out or home they stand thus:—

TABLE I.

		Days.	Hours.	Mins.
1	"Etruria" . . .	6	5	31
2	"Umbria" (sister ship) .	slightly longer.		
3	"Oregon" . . .	6	10	35
4	"America" . . .	6	13	44
5	"City of Rome" . .	6	18	0
6	"Alaska" . . .	6	18	37
7	"Servia" . . .	6	23	55
8	"Aurania" . . .	7	1	1

It will thus be seen that from the 15 days' passage or thereabouts of the earliest Atlantic steamers, we had got down in the days of the "Scotia" to about 9 days, in the "Britannic" to $8\frac{1}{4}$ days, and at the present time we have got to $6\frac{1}{4}$ days,—with seven ships afloat that have done the passage under seven days and capable of making their average passages range between $6\frac{1}{2}$ and $7\frac{1}{4}$ days.

Ranged in order of gross tonnage these eight vessels stand as follows:—

TABLE No. 2.

1. "City of Rome"	8,144
2. "Oregon"	7,375
3. "Aurania"	7,269
4. "Servia"	7,212
5. "Umbria"	7,129
6. "Etruria"	7,100
7. "Alaska"	6,586
8. "America"	5,528

Here the "America" shows to advantage, for while being eighth in size she is fourth in point of speed, and from what I can learn, although I have no authenticated details on the subject, I believe she is economical in coal consumption.

I may perhaps be permitted here to say that one of the most difficult subjects in connection with the propulsion of ships on which to get absolutely accurate data is that of coal consumption.

The records of six or eight hour trials for the purpose of ascertaining the coal consumption are absolutely worthless, as all shipbuilders and engineers know, and so far as English ships are concerned they are never attempted. Foreign owners frequently stipulate for such trials in their contracts with English shipbuilders, and get wonderfully economical results on paper, but the fact that the trials only extend over a few hours renders them valueless, however carefully the coal may be weighed during that period.

An authentic record of the absolute quantity of coal consumed, say by each of the above eight fastest Atlantic Liners, together with their average indicated horse-power on the voyage for a series of voyages, would be extremely valuable, but that I cannot pretend to lay before you.

I have given, on Table 3, Page 164, the approximate consumption per indicated horse-power per hour for a number of ships, and perhaps some of the gentlemen present may, in the course of the discussion, afford us information which will enable the Table in this respect to be made more complete. This table, I may mention, affords valuable data, for it gives, in addition to the dimensions,—the draught of water (moulded), the midship area, the displacement, the indicated horse-power, the speed on trial, the co-efficients for the lines both from the block or parallelopipedon, and also from the midship section prism, together with the length and angle of entrance obtained by Kirk's rule, the Admiralty displacement co-efficient—a co-efficient which we think an improvement on the Admiralty co-efficient, and which has been for sometime used in our drawing office—together with the approximate coal consumption per day and per indicated horse-power per hour.

This table, as will be seen, contains some of the most important of the Atlantic Liners, and also a number of other typical ships, which will add a variety to its interest and a value to it for reference. I will here mention, in reference to the co-efficient I allude to, and which is contained in the thirteenth column of the table, viz. :—

$$\frac{\text{Dis}^{\frac{2}{3}} \times \text{speed}^3}{\text{I.H.P.} \times \sqrt{\frac{\text{entrance.}}{10}}}$$

that it generally comes out for ships of similar type more nearly a constant in the true sense of the word than the corresponding Admiralty constant. As an example, we have the curves of resistance and horse-power for the "City of Rome" and the "Normandie," the latter a large vessel of 6,000 tons, which we built for the Compagnie Générale Transatlantique. In these two ships the co-efficient of fineness and the form of the lines pretty closely resemble each other below water, and if we take from the curves the corresponding

speeds and horse-powers, and work out the constants by the two systems, we have at 14 knots the Admiralty constant for the "City of Rome" 322·2, and for the "Normandie" 304·8, and taking the modified form of constant, the "City of Rome" gives 253·7 and the "Normandie" 251·9, which, as will be seen, is much closer together; similarly, at 15 knots the Admiralty constant, for the "City of Rome" is 310, and for the "Normandie" 295·2, while the modified constant comes out for the former ship 245, and for the latter 244. At 16 knots, for the "City of Rome" the Admiralty constant comes out 297·6, and for the "Normandie" 282·8, while the modified constant comes out for the two ships 234·4 and 233·7 respectively.

It may be mentioned that in these two ships the engines are of a similar type, being three-crank tandem engines, and the propellers have in both pitch and surface practically the same proportions to the power and speed. The value of these modified constants will probably be found to increase as the speeds increase up to the limit and beyond that point at which wave resistance becomes an important factor.

But, turning from the question of speed for a moment, as I wish to refer to it again later on, I would say a few words on the question of the strength, stability, safety and internal arrangements of this class of vessel; and first, as regards strength, I may say at once that although we have got to ships of such enormous size, I am sure there is no ground for apprehension in regard to any of them on the score of danger from structural weakness under the ordinary circumstances of heavy weather at sea—I say this not only as the result of recent calculations, but of a comparison of the scantlings and arrangements of ships of the present day and the material they are built of with ships of 15 or 20 years ago.

It is now some 12 or 14 years ago since I was very largely engaged, while in the employ of "Lloyd's Register of Shipping," in comparing the scantlings of ships then afloat of different sizes, both classed and unclassed, and in prosecuting a series of investigations to determine approximately the stresses to which such ships were liable at sea and their relative strengths to bear them. Those calculations at the time were chiefly directed to longitudinal strains and stresses, but in later years I dealt with some of the other strains, transverse, local, &c.

I may mention, that at the time I refer to, I was struck with one important fact that arose from the investigations; which was that there was a marked diminution in the structural strength of iron ships as their sizes increased. After trying a number of ships of different sizes upon waves of their own length, I arrived at a few formulæ which have since been used for purposes of comparison, and which gave approximately maximum bending moments to which merchant vessels might be liable at sea tending to produce hogging and sagging. And after taking the scantlings for different vessels and testing them as a girder to resist these bending moments, I found that the tension on the upper works

of some of the larger vessels then afloat amounted to more than double that of the usual run of small vessels, and that it was capable, under certain conditions of wave motion, of amounting to between eight and nine tons per square inch of iron; and, feeling somewhat alarmed at the results of these calculations, I used the following words in a Paper read by me before this Institution in 1874:—

"These forces are not sufficient in themselves to cause rupture in a vessel well built, "and of good materials, but they may be sufficient to cause very considerable straining "which if not attended to in time must weaken the vessel to the point of danger. It is a "long time now since we heard of any vessel breaking off amidships through the strains "afloat, but we do hear very frequently of large vessels being considerably strained, and of "timely precautions being taken to strengthen them even at great cost. Among the deduc-"tions to be drawn from this Paper the most important is I think that the longitudinal "strength of large iron steamers requires the most careful and anxious precaution. We "are trespassing on the margin of surplus strength to an extent which creates in my mind "an uncomfortable feeling, especially in view of the enormous strides which are now being "made from 400 to 500 ft. in length." That was written 12 years ago, and I went on to say "with the 'Great Eastern' before our eyes, however, we need have no fears that the "present rapid growth of vessels will be checked by want of strength in their structure. "The only element of danger lies in the absence of data as to the magnitude of the strains "to be encountered."

As a matter of fact some of the steamers to which I pointedly alluded in the foregoing words were strengthened very considerably, and have been doing their work since satisfactorily. I need not recapitulate here the modes of calculation which I employed at that time, or stop to discuss the further advances which have since been made, but it is a satisfaction to me to know, as I do from similar calculations made upon some of the largest and most modern of our Atlantic liners, that there are no grounds now for such apprehensions, as I felt then, although we have very considerably exceeded the 500 ft. limit I was then contemplating, and have got in fact to within about 100 ft. of the length of the "Great Eastern" herself.

I have before me the calculations for three of the largest of these vessels, two of them of iron and the other of steel, and I find in the case of the iron ones the maximum tension on the gunwale during the greatest hogging strains likely to be endured at sea would not exceed about six tons per square inch, while in the case of the steel ship it is only about $6\frac{1}{2}$ tons. These strains are well within the limits of safety, and a comparison of the scantlings of these with the others to which I have been alluding, justify me I think in the assertion I have just been making as to their general safety from a structural point of view. The sections of these three ships are given, see Plates XII., XIII. and XIV., with their principal scantlings. It will be seen from these sections that the three ships differ

materially in their mode of construction. In the case of Plate XII., which represents the "City of Rome," the largest of the three, the main framing of the vessel is entirely transverse with very heavy keelsons in the bottom, and large partial bulk heads or web frames; and the outside plating is arranged on what is termed the edge to edge principle, with a great portion of it doubled.

In the next section, Plate XIII., is the "Servia," which is built of steel, and in her the bottom is built on the longitudinal cellular system, the first application I believe of this system to an Atlantic Liner.* We have since fitted the "Normandie" with the cellular bottom somewhat similar, and are building two 6,000-ton ships at the present time for the Pacific Steam Navigation Company in a somewhat similar way. The plating of the "Servia" is of the usual alternate outer and inner strake system, partly doubled, while the third section, the "Oregon," Plate XIV., approaches more nearly to the ordinary system of framing and plating usually adopted, but it will be seen that she is well tied in the bottom by very heavy intercostal and plate keelsons, as well as in the top by heavy stringers and sheer strakes, with much of her plating doubled, and heavy web frames inside.

I thought these samples would be sufficient, or I might have gone through the structural strength of others of the vessels to which I have alluded.

Next to structural strength, the point which probably most exercises the public mind in connection with passenger steamers, is that of stability; and here, I think, shipbuilders are at present in advance of what they were some years ago. Very few builders at the present day, who would be at all likely to be entrusted with the building of large passenger steamers, omit to go thoroughly into the proper scientific calculations to ascertain what the stability is likely to be, or omit to take the precaution of heeling the vessel in dock after the engines and boilers are on board for the purpose of ascertaining accurately the position of the centre of gravity and recording the results in their drawing office.

Many owners, too, at the present day require from the builders full details of the results of such investigations, and the consequence is that a more steady control is exercised over this question than formerly. What accidents have happened with passenger steamers have arisen not so much from the faulty stability of the ships themselves as from the carelessness or the ignorance of those on board. Most ocean-going passenger steamers when light are tender, and it sometimes happens that a large amount of loose water is allowed to remain under the ceiling, and especially in the long engine and boiler spaces, which renders the vessel far more tender than she otherwise would be, and renders it liable when weights are put in on one side more than on the other, or when there is a strong wind blowing, for the ship to take a considerable list, in which case, unless all the ports are closed, there is the danger of capsizing. We know what took place in the case of the "Austral" in Sydney

* When writing this passage I had forgotten the "Parisian" and the "Buenos Ayrean."

Harbour, and I have known two or three cases where from the cause I have just mentioned a somewhat similar accident might easily have happened.

This question of stability will have to be carefully watched and studied within the next few years, because there is a tendency at present towards a rapid increase in the proportion of beam to length, and as the draught of water in these large ships is limited, we must be careful that in seeking higher speeds with increased beam we do not get too much stability, and so render the vessels heavy rollers, and very uncomfortable as passenger ships. It is possible the future may see vessels of greater beam than any yet afloat in the merchant service, but, if so, it is almost inevitable that they will have to be made higher out of water in order to render them easy and comfortable at sea, but even that has its limits. Perhaps it is as well to give an extreme case, and here I will make use of our old friend the "Great Eastern." I have shown on Plate XV., an outline midship section of six of our principal passenger steamers, including the "City of Rome," "Servia" and "Oregon," and on the same diagram is an outline of the midship section of the "Great Eastern." Now, for the purpose of trading, it is quite clear that the "Great Eastern" cannot be loaded very much deeper than other ships, while her beam is half as great again, and the consequence is that her stability, as compared with our modern passenger ships, is so excessive that she is bound to be a tremendous roller among the long heavy seas in the Atlantic. Her metacentric height when loaded was, I believe, stated by the late Mr. Froude to be as much as 8·7 feet, which is from three to four times as much as is thought sufficient for ships in the present day, or consistent with their easy behaviour at sea.

Of course, if it were not for her excessive height out of water she would be still worse, but the point I wish to bring out is, that as we extend the beams of our passenger ships while limited as we are to draught of water, we shall be almost necessarily forced into deeper vessels, higher out of water. This is an advantage in one sense and a disadvantage in another. In the first place, it is an advantage because it keeps the upper deck higher and dryer, and it adds to the safety and comfort of the ship, and it will enable a greater number of passengers to be carried, or higher and finer saloons and state-rooms. On the other hand, the resistance offered to a headwind will become greater; but this, perhaps, can be neutralised by reducing some of the top hamper; and this leads one to consider to what extent in the near future it is likely that masts and sails and other top hamper in our passenger steamers can be done away with safely. One step and one step only can justify making a clean sweep of them,—except such poles as are necessary for signalling and other such purposes,—and that is the adoption of twin-screws, which I venture to think we are rapidly approaching.

I for some time feared that nothing but a serious disaster arising from a breakdown in the engines or the shafting or propeller of a single screw ship in a heavy storm would bring the advantages of twin-screws from the point of view of safety sufficiently to the front

to ensure their being seriously considered on their merits; but I do not think now that a disaster is necessary for this purpose, as I know the matter is being seriously discussed by shipowners in various directions, and is the subject of work and investigation in the drawing offices of shipbuilders.

I know, speaking for ourselves, that we have done more in the way of planning and designing for the adoption of twin-screws lately, than for any other mode of propulsion, and this chiefly for passenger steamers. We have, perhaps, advanced as far as anyone in rendering the single screw system as safe as possible for very large steamers, and in proof of this I may instance both the "City of Rome" and the "Normandie."

In both cases the engine was of the three-crank tandem type, with all parts interchangeable; and in the event of either engine getting deranged, it could be easily disconnected and the vessel worked with 2 cranks and 4 cylinders, or like any ordinary two-crank compound tandem engine. In the case of the "Normandie" the system was carried out further than in the "City of Rome," for in that ship the condensers, pumps, &c., were all made separate for each engine upon each crank; and in both cases all parts were interchangeable.

There, of course, we had many of the advantages of the twin-screw, but were still at the mercy of a broken tail shaft or propeller, and at the mercy of the gale as long as it lasted, if the crank shaft or any other heavy part got disabled. In the case of twin-screws, however, in the event of an accident to one set of engines, propeller or shafting, the ship could not only be kept under control, but could be steamed at about three-fourths of her normal speed with the other engine; and in the meantime, unless it was the tail shaft or propeller that had gone, the other engine could soon be got into working order; so that with a twin-screw vessel, with say two sets of engines on the triple-expansion principle, with three cranks, it is quite possible to so arrange them as to put it beyond the bounds of human probability that the ship could be disabled in her machinery at sea. This in itself is an enormous and almost overwhelming advantage for passenger steamers that carry so many souls on board; but more than this, the twin-screw system so lends itself to subdivision into water-tight compartments that a passenger ship fitted with twin screws might be rendered unsinkable. Besides this I believe that, as a matter of economy and efficiency at sea, there are sufficient grounds for believing that the twin-screw will have the advantage over the single screw.

Nobody worked so hard, to impress upon the public of his day the advantages of twin-screws, as the late Mr. J. Dudgeon, the well known Thames shipbuilder. His firm gave most interesting particulars of steam trials made with a number of their twin-screw vessels to this Institution over twenty years ago, and I think they will be found recorded in the Transactions for 1865. They boldly claimed fifteen per cent. advantage for the twin-screw over any other method of propulsion in those days. For one reason or another the statements and the proofs did not carry the weight which we think they

might and should have done. It is true, at the time, the prevailing prejudice, even with single screws, was in favour of getting as large a diameter of screw as possible, and vessels were made in many cases unduly deep at the stern for the purpose of getting a large single screw; whereas, at the present time, to develop the same power, they would not think of going to the same extent. The Admiralty, so often accused of lagging behind the mercantile marine in matters of improvement connected with propulsion, cannot be accused in this case of doing so; for they early, although not nearly so early as Mr. Dudgeon and a few others, adopted the system. The primary reason was, of course, the necessity for manœuvring in small circles, to give or avoid the ram; and whether foreseen or not, the result has been, that in war ships they have got far better results as a mere matter of propulsion from the twin screw than they ever did from the single screw. This was clearly enough proved by Mr. White in his Paper read before this Institution in 1878, on "The Efficiency of Single and Twin Screw Propellers." The figures rested chiefly upon the full lined Ironclads of the Navy. The first experiment of importance with twin-screws for a fine lined and very high speed vessel for the Royal Navy was in the "Iris," the particulars of which have often been quoted. It is well known that the vessel was at first what is termed overscrewed, and did not get within a couple of knots of what was expected of her, and what she afterwards obtained with the same power and modified screws. I am not sure that a further change in the same direction, viz., of diminished diameter and increased pitch would not be found to give still better results.

We are, I believe, on the eve of getting much valuable data from the Admiralty experiments with a number of fine lined cruisers built or building to be fitted with twin-screws; and I hope in vessels like those of the "Scout" class, where they have so many ships of the same type, the Admiralty may be advised to make them the means of acquiring useful information on the subject of the proper dimensions and form of propellers for twin-screw ships.

I am not one of those who attach much importance to the particular form of the blade either in single or twin-screws, as I believe so long as the disc area, the surface and pitch are properly adjusted to the speed of the vessel, and to enable the engines to use, at the maximum speed, just the full quantity of steam that you can make in the boilers, you have got pretty nearly as far as you can get. To fix these dimensions of the propeller accurately at the present time, and without further knowledge of the action of the screw on the water is, I think, impossible. All the rules and formulæ are empirical. The best one I know is given on Table No. 4, Page 165, which I believe is due to Mr. Thom, the head of our engineering drawing office, and at present acting manager, who has used it for some years in practice. This formula is based upon the assumption that the area of the propeller disc should be proportional to the indicated horse-power, divided by the cube of the speed; and the same with the projected area of the propeller, and also the surface.

It will be seen from this simple law that you can obtain constants for the disc area, for the projected area, and for the expanded area, from what in principle is the same formula.

I have mentioned this formula as having been used for some years by Mr. Thom, because the first time I have seen it published or heard of its use is in the valuable little book published by Mr. S. W. Barnaby last year, in which the formula is used and in which it is implied that it is something new which the author was indebted to Mr. Thornycroft for permission to publish. In this Table No. IV. it will be seen that there are ships of all sizes and types, both single screw and twin screw, varying from 540 ft. long to 138 ft., and the constants run with one or two exceptions with wonderful regularity. The chief exception is the case of the "Iris" with her first propellers, where it will be seen at once that there is something abnormal about them, and even with the modified screws for the "Iris," judged by the other ships on the list there is something still out of the common, and this gave rise to my remark in an earlier part of this Paper that further experiments with different screws, might and probably would yet bring out better results for that ship.

There is another exception in the Table which I might point out, but it is not so striking as the "Iris." It is in the case of the "Kow Shing" where the disc constant is exceptionally small, and the surface constant high. This arose from the exceptional circumstances of the case. We had a very limited draft of water with a single screw, to develop a very high power, and we were constrained to minimise the diameter of the propeller. When on this question of propellers, I may mention a curious instance where there is a disagreement between what may be termed some of our most careful investigators and some of our most experienced sailors. I refer to the effect produced on a single screw-ship moving ahead under the influence of the screw with rudder kept quite amidships. Professor Osborne Reynolds, F.R.S., has proved experimentally and has explained it scientifically that the upper blade of a propeller that is totally immersed, does the most work in propelling the ship, and hence has the greatest pressure upon it, and that in consequence, a single screw steamer, with a right-handed screw, that is, one that has the blades descending on the starboard side with the ship going ahead, must have a tendency for the stern to move over to port and the bow to starboard. The popular belief is that the lower blade of the propeller is the most effective and that under similar circumstances the stern of the ship would go to starboard and the bow turn to port. I have never tried the matter actually on board a single-screw steamer myself, but theoretically, it should be undoubtedly in favour of the view of Professor Reynolds, a view which has been repeated as a matter of fact by Mr. Barnaby and others. But it is no less a fact that ships' propeller shafts are sometimes set at an angle to counteract this very tendency on the supposition that the lower blade and not the upper blade is the most effective and that the ship's head has a tendency to port instead of starboard. It would be interesting to hear

the views on this point of some of the practical gentlemen present who have had curiosity enough to test the tendency under ordinary circumstances with the propeller fully immersed.

One or two other points in connection with twin-screws, I must mention, before leaving the matter of propulsion. What experience I have had with twin screws, leads me to believe that there will be less racing in rough weather with them than with single screws and that, consequently, they will make more uniform passages. There is also the fact that if the rudder gets disabled you have the ship perfectly under control.

Another point often raised is the difficulty of entering and leaving docks and the danger of injury to the propeller against dock walls with twin screws. This, I think, would soon right itself, when the captain gets to understand how to handle such ships properly.

The first twin-screw steamer I was concerned in the building of broke her propeller the first time she got alongside a pier, but it was a lesson to the captain and she has never lost another from the same cause. I must return however to the question of subdivision as arising from the use of twin screws.

With single screws you cannot possibly divide your engine and boiler space into compartments so as to render the ship safe against sinking by collision even with small vessels. With twin screws you can carry a watertight middle line bulkhead right through both engine and boiler compartments, and you can as at present divide the engine room from the boiler room by a transverse bulkhead and also, if necessary, subdivide the boiler space by an extra transverse bulkhead. The same precautions would of course be taken, as at present, to render the coal bunkers watertight, but the case of the " Oregon " shows that this is not sufficient. The difficulties in the way of carrying out a complete sub-division by means of a water-tight middle line bulkhead are I know not inconsiderable, especially, if it is to be done in such a way and to such an extent as to render it a part and parcel of the structural strength of the ship as well as for the purposes of subdivision. For instance to be effective and to ensure safety it must be extended above the main or middle deck of the ship, and forward and aft beyond the limits of the engine and boiler space. This means in Atlantic and other important passenger steamers that it must go through the main saloon, and in fact extend to the upper deck throughout about three-fourths the length of the ship. The idea of running a middle line watertight bulkhead through the main saloon at first rather staggered me, but upon working it out I found that it simply meant two dining rooms instead of one, and each capable (owing to the limited height between decks) of better artistic treatment, lighting and comfort than is possible in a single huge saloon, and likely in my opinion to be more popular with passengers. This Paper is already too long for me to attempt to discuss the altered arrangements in respect to deck-houses, galley, and steward's arrangements that may become necessary, but I can only say that it is not only possible but practicable, and I believe highly desirable.

Apart however, from these domestic arrangements (if I may so term them), is one very important question as affecting strength and safety. Take the case of any Atlantic passenger steamer afloat, say one of the strongest, capable of doing her ordinary work safely for years. Suppose that a ship in Mid-Atlantic is run into by a steamer or sailing ship that strikes her high above water midships, say on the starboard side, and breaks through the upper deck sheerstrake and stringer. Practically the upper flange of the girder is gone, and if that ship has to endure waves and roll to port she is likely to go down by breaking amidships. A middle line bulkhead, properly stiffened with heavy stringer or tie plates attached on the upper deck would obviate this, and might as a matter of structural strength, apart even from subdivision, save the ship.

These are some of the points that have long run through my mind, and I hope you will not think them too crude, or too much wanting in the element of actual demonstration.

We have seen many changes in the Atlantic. People are asking what the next change, is to be. I think every one is agreed that triple expansion engines are inevitable, and I think there is also a tendency towards twin-screws. Forced draught I am not so sure about at present. The White Star Line have made vast strides by their introduction of the midship saloon, revolving chairs, &c., and the Inman Company, among other improvements, in the introduction of electric lighting. We are all watching for the direction the next start is to come from. For my own part I can only say that I should like to be associated with it, if it is in the direction of high speeds, twin-screws, a middle line bulkhead and perfect sub-division. I do not say it with any spirit of envy, but the naval architect and marine engineer whose luck it may be to have an opportunity of taking the lead in this direction to such an extent, and who can develop it as ably, as Mr. Bryce Douglas did with the single screw "Greyhounds" from the days of the "Arizona" and "Stirling Castle" to the present time, will be not only a fortunate man himself, but I verily believe will be recognised as a benefactor to his country.

It has been my object to treat this subject in a general and impartial way, free from particular reference either to shipbuilders or shipowners. I regret I have had to leave out of notice many important lines of steamers and important trades on the Atlantic, for some of which I am at present building, but the limits of space and time have kept me within comparatively narrow limits of choice in such an important subject as the Atlantic Trade.

Year.	CUNARD LINE.							
	P.S. "Scotia."	"Servia."	"Aurania."	"Oregon."	"Etruria."		Umbria."	
					Outward.	Homeward.	Outward.	Homeward.
	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Min.
1863	8 4 30	...	...	...	...	...	...	...
1875	...	...	...	...	...	...	...	...
1876	...	...	...	...	...	...	...	...
1877	...	...	...	...	...	...	...	...
1878	...	...	...	...	...	...	...	...
1879	...	...	...	...	...	...	...	...
1880	...	...	...	...	...	...	...	...
1881	..	...	...	...	...	...	...	...
1882	...	...	...	...	...	...	...	..
1883	...	...	...	...	...	...	...	...
1884	...	6 23 55	7 1 1	6 10 35	...	...	1 voyage. 7 16 22	1 voyage. 6 19 8
1885	...	...	...	...	Av. 9 voyages. 6 19 43	Av. 9 voyages. 6 13 59	Av. 2 voyages. 7 18 30	Av. 2 voyages. 6 18 15
1886	...	...	...	...	4 6 11 43	3 6 14 41	4 6 19 33	4 6 12 45
			GRAND	AVERAGES.	6 15 43 13 voyages.	6 14 20 12 voyages.	7 10 8 7 voyages.	6 16 43 7 voyages.
Quickest .	P.S.8 4 30	6 23 55	7 1 1	6 10 35	6 5 31	6 7 32	6 9 22	6 12 8

INMAN.	WHITE STAR.				ANCHOR.		NATIONAL.		GUION.	
"City of Berlin."	"Britannic."		"Germanic."		"City of Rome."		"America."		"Alaska."	
Outward.	Outward.	Homeward.	Outward.	Homeward.	Outward.	Homeward.	Outward.	Homeward.	Outward.	Homeward.
Dy. Hr. Min.	Dy. Hr. Min.	Dy. Hr. Mn.	Dy. Hr. Mn.	Dy. Hr. Min.	Dy. Hr. Mn.	Dy. Hr. Mn.	Dy. Hr. Mn.	Dy. Hr. Mn.	Dy. Hr. Mn.	Dy. Hr. Mn.
...	...	...	...	...	...	...	...	...	...	...
7 18 2	...	...	...	...	...	...	...	...	...	...
...	Av. 6 voyages. 7 18 26	Av. 6 voyages. 7 20 56	Av. 8 voyages. 8 11 40	Av. 9 voyages. 8 1 8	...	...	...	...	...	...
7 14 12	Av. 11 voygs. 8 10 22	Av. 10 voyages. 8 0 6	Av. 7 voyages. 8 3 29	Av. 7 voyages. 8 4 40	...	...	...	...	...	...
...	8 9 7 26	8 10 4 53	8 11 8 32	8 10 4 57	...	..	...	...	...	...
...	8 10 9 17	8 10 2 48	8 9 13 40	8 10 8 43	...	...	...	...	...	...
...	8 9 8 29	8 8 4 9	8 10 20 17	8 9 8 40	...	...	...	...	...	...
...	8 9 8 29	8 9 9 34	8 10 9 57	8 11 9 35	...	...	...	...	...	...
...	8 11 16 59	8 10 1 7	8 10 14 29	8 10 4 55	...	...	...	...	...	...
...	8 10 10 32	7 10 22 6	8 10 11 3	8 10 6 12	Av. 5 voyages. 7 5 55	Av. 5 voyages. 7 2 55	...	...	6 21 38	Av. 3 voyages. 6 20 42
...	8 10 14 6	7 10 23 30	8 7 4 20	7 6 21 24	7 8 10 9	7 8 3 39	Av. 2 voyages. 6 16 41	Av. 3 voyages. 6 17 25	Av. 2 voyages. 6 23 15	6 18 37
...	8 10 8 37	8 10 0 11	8 11 5 40	8 11 2 37	7 8 3 55	6 8 23 45	...	...	...	...
...	...	...	...	...	7 4 3 5	7 3 7 16	...	...	...	...
7 16 7 2 voyages.	8 9 36 95 voyages.	8 1 48 93 voyages.	8 10 39 93 voyages.	8 5 13 93 voyages.	7 5 31 25 voyages.	7 3 24 24 voyages.	6 16 41 2 voyages.	6 17 25 3 voyages.	6 22 56 3 voyages.	6 19 39 4 voyages.
7 14 12	7 10 53	7 12 41	7 11 37	7 15 17	6 18 40	6 18 0	6 15 22	6 13 44	6 21 38	6 18 37

TABLE III.

NAME.	Length.	Breadth.	Moulded Draft.	Midship Area.	Displacement.	Indicated H.P.	Speed.	Block Co-efficient.	Midship section Co-efficient.	Prismatic Midship Section Co-efficient.	$\frac{D^{\frac{2}{3}} \times S^3}{I.H.P.}$	$\frac{D^{\frac{2}{3}} \times S^3}{I.H.P. \times \sqrt{ent.}}$ 10.	Kirk's System. Length of Entrance.	Kirk's System. Angle.	Coal Consumption. Per Day.	Coal Consumption. Per I.H.P.	Cylinders. Diameter.	Cylinders. Stroke.	Boilers. Heating Surface.	Boilers. Bar Surface.	Working Pressure.
	Ft. In.	Ft. In.	Ft. In.														Ins.	Ins.			Lbs.
"City of Rome"	542 6	52 0	21 5½	1,031	11,230	11,890	18·235	·649	·925	·702	255	201·3	161·27	8° 29′	185	2·2	3 @ 46 3 @ 86	72	29,286	1,398	90
"Normandie"	459 4	49 11	19 9¾	892	7,975	6,959	16·66	·614	·901	·681	265	219·5	146·41	8° 44′	148	2	3 @ 35 7/16 3 @ 74⅞	67	21,404	756	85·2
"Furnessia" .	445 0	44 6	22 2½	893	8,578	4,045	*14	·682	·903	·755	284	273	108·7	10° 28′	97	2·2	49—100	66	10,396	440	90
"Arizona" .	450 0	45 1½	18 9	758	6,415	6,300	17	·589	·895	·658	269·2	217	153·79	7° 30′	..	..	1 @ 62 2 @ 90	66	..	..	90
"Orient" .	445 0	46 0	21 4½	904	7,770	5,433	15·538	·621	·919	·676	270·8	225	144·17	8° 21′	..	..	1 @ 60 2 @ 85	60	..	..	75
"Stirling Castle"	420 0	50 0	22 3	990	7,600	8,396	18·4	·569	·889	·639	286·8	233·7	151·3	8° 22′	..	..	1 @ 62 2 @ 90	66	21,161	787	100
"Elbe" . .	420 0	44 9	20 0	807	6,350	5,665	16·571	·591	·901	·655	275·5	229	144·6	7° 56′	..	..	1 @ 60 2 @ 85	60	..	..	..
"PembrokeCastle"	400 0	42 0	17 0	648	5,130	2,435·8	13·25	·623	·9	·692	284	258	122·9	8° 49′	44	1·7	43 & 86	57	7,896	288	90
"Umbria and Etruria"	500 0	57 0	22 6	1,090	9,860	14,321	20·18	·538	·896	·637	260	191·8	184	6° 52′	315	2·1	1 @ 71 2 @ 105	72	38,817	1,606	110
"Aurania" .	470 0	57 0	20 0	1,020	8,800	8,500	*17·5	·575	·942	·632	266	204·6	170	8° 38′	215	2·2	1 @ 68 2 @ 91	72	23,284	1,001	..
"America" .	432 0	51 0	26 7	1,272	9,550	7,354	*17·8	·57	·935	·608	345	265	169·3	8° 32′	185	..	1 @ 63 2 @ 91	66	..	882	..
"Oregon" .	501 0	54 2	23 8	1,150	11,000	13,300	18·3	·599	·849	·67	227·9	190	164·3	9° 39′	310	2·2	1 @ 70 2 @ 104	72	38,047	1,428	110
"Servia" .	515 0	52 0	23 3½	1,046	10,960	10,300	*16·9	·610	·862	·71	231	192	145·3	10° 42′	205	2	1 @ 72 2 @ 100	78	27,483	1,014	..
"Scotia, P.S."	369 0	47 6	19 9	867	6,000	4,632	*14·31	·605	·92	·65	208·9	186	126·8	13° 21′	168	3·4	2 @ 100	144	..	..	..
"Alaska" .	500 0	50 0	21 0	949	9,210	..	..	·614	·904	·679	..	..	160·23	8° 2′	..	..	1 @ 68 2 @ 100	72	..	..	100
"Aller" . .	438 0	48 0	21 0	907	7,447	7,974	17·9	·590	·899	·656	277	225	150·6	8° 10′	..	..	1 @ 44 1 @ 70 1 @ 100	72	22,630	799	150
"Ems" . .	430 0	46 10	20 7½	877	7,030	7,251	17·55	·593	·907	·652	273	223	149·4	8° 40′	..	..	1 @ 62 2 @ 86	60	19,700	780	100

* Mean speed of a voyage across the Atlantic Ocean.

TABLE No. IV.

Particulars of Propellers and Constants.

SHIP.	Length of Ship.	Disc constant.	Proj. Surf. constant.	Feet per sec. Speed of tips.	
"City of Rome"	542	220	69	4,715	
"Normandie"	459	250	66	4,099	
"Furnessia	445	223	69	3,654	
"Eden"	300	211	64	3,080	
"Yorouba"	270	213	63	3,202	
"Taygete...	260	238	56	3,166	
"Kow-shing"	250	171	69	3,369	
S. Y. "Monarch"	152	221	65	4,040	
,, "Aries"	38	179	56	2,986	
Twin-screw "Fenella"	200	244	64	2,890	
,, H.M S. "Fearless"	220	277	67	5,022	Estimated with a speed of 17·5 knots, and 3,370 I.H.P.
,, ,, "Iris" ...	...	*454	*135	...	
,, ,, ,,	300	412	122	...	With the first Propeller at the estimated speed of 17·5 knots and 7,000 I.H.P.
,, ,, ,,	300	346	99	4,961	With 4-bladed modified Griffith's on actual trial.
,, ,, ,,	300	439	82	5,309	With 2-bladed modified Griffith's on actual trial.

* Constants obtained from first propeller calculated from a speed of 18·5 knots and 7,500 I.H.P.

$$\text{Disc constant} = \frac{\text{Area of propeller disc} \times \text{speed of ship in knots}^3.}{\text{I.H.P.}}$$

$$\text{Projected area constant} = \frac{\text{Projected area of propeller} \times \text{speed of ship in knots}^3.}{\text{I.H.P.}}$$

Expanded Area constants may be obtained and used in the same way.

DISCUSSION.

Mr. Alfred Holt (Member): My Lord, I have been tempted to come forward very much by the last words you uttered, saying that possibly the discussion of to-day might be continued to-morrow. To my mind the discussion on the last most interesting Paper by Mr. Parker was somewhat incomplete. With regard to Mr. John's Paper just read, for which we must all thank him, I would wish to say a few words which may possibly form the subject of further discussion. In the main he advocated for greater speed, as I understood, the system of twin-screws, and for greater safety middle line bulkheads, and perfect sub-division. Twin-screws do not appear (and I say it with all deference to the greater knowledge of many now present) to have produced the result that one would have expected. There seems to be ample opportunity of obtaining a sufficient area for propulsion with a single screw, and our fastest vessels, when of reasonable draught of water, have found no difficulty from this cause. I therefore differ from him on this particular point, not being aware of any evidence pointing to the inefficiency of a single screw. If we are to have greater speed in the Atlantic, one change which has not been alluded to at all, and which I submit will probably be recognised by the meeting as of greater efficacy for speed than either twin-screws or triple expansion engines, is the abolition of cargo in passenger vessels—that is I suggest the carrying of cargo in one vessel and passengers and mails in another. I feel convinced that in the present state of mechanical knowledge this is the only discernible process by which great increase of speed can be expected, and this not so much because of the weight of cargo which is carried—because these large and fast vessels do not frequently carry very much cargo, but because they are prepared to carry it, and therefore are built very much heavier than would be necessary if passengers alone were contemplated. Further, in order to carry this cargo, they are built of a form giving very great displacement in the bottom part of the vessel, and with much heavier scantlings than would be necessary for strength if passengers alone were to be embarked. Now, these considerations act and re-act as it were. The lightness of the structure would allow a more yacht-line form of ship with a greater rise of floor. This would bring about easier motion at sea, and the cargo holds would also put at the disposal of the designer of the ship for passenger purposes or engine spaces, an immense area at present rarely and very insufficiently used for freight. Further, steam-winches, hatchways, and all similar cargo necessities which interfere most awkwardly with the arrangement of the cabins (as anyone who has designed the saloon and sleeping accommodation of a passenger steamer knows) would disappear. As the lightness of the structure, which is synonymous with smaller displacement, would render such power as the vessel was provided with very much more effective for propulsion. If a discussion on these points could be raised, I think it would be valuable, because the course I suggest appears to me to be the sole present available one from which we may reasonably expect considerable increased speed in the near future. Something like half to three-quarters of a day might, I feel sure, be taken out of our best performances by the cessation to carry cargo. Moreover, I do not believe freight pays in such vessels, and this may turn out a stronger reason than any for a move in the direction which I have indicated. Then with regard to Mr. John's advocacy of middle-line bulkheads I must differ from him somewhat. I imagine a vessel divided in that way and receiving a serious blow on one side in a collision, I apprehend she would soon be in a most dangerous condition. It would be better if the transverse divisions were multiplied so that a small length of the vessel might be flooded completely rather than that a larger length on one side only. I should think that the danger to the passengers and the ship's company would be increased by longitudinal bulkheads. These are the only points upon which I wish to address the meeting.

Mr. W. H. White (Vice-President): My Lord, I would not have intervened in the discussion at this stage, only that it is impossible for me to be here to-morrow. I would much rather have sat still and listened to what shipowners, and particularly those owning Atlantic steamers, have to say about them, but as is well known to all the members of this Institution, the subject of twin-screw propulsion in deep draught ships has been of special interest to me for many years. In 1878 I dealt with it as fully as I then could on the basis of Admiralty data, and I then ventured to say practically everything in favour of twin-screws which Mr. John, with his special experience in merchant ship construction, has said here to-day. In twin-screw ships there is greater safety obtainable through more minute sub-division, as well as less risk of total disablement, and, probably, a greater efficiency of propulsion, taking into account all the circumstances that obtain at sea. In addition, there is a better outlook for the future, with its inevitable tendency to higher speeds, when either twin-screws or multiple screws are substituted for single screws, for these higher speeds necessarily involve the development and utilisation of much greater engine power. The twin-screw ships which Mr. Dudgeon built, and to which Mr. John refers, were *light draught* ships. Twin-screws began in association with light draught as a substitute and a rival for paddles, and Mr. Dudgeon certainly obtained very good results in vessels of moderate draught. In the Navy the principle was applied in the mastless type of ships in association with *deep draught*, and it is perfectly well known that the results obtained with the earliest deep draught twin-screw ships were surprisingly good. The change from single-screw ships carrying masts and sails to the twin-screw type without sail power, was made with very great deliberation and after full consideration; but the results obtained in the "Devastation" and the "Thunderer" led to the carrying on of the system by my friend Sir Nathaniel Barnaby into the "Alexandra" and other rigged ships. The system has been continuously developed, and we now have no new ships building for the Navy which are not driven by twin-screws, except the small cruising vessels, wherein sailing is of great importance. We have passed on from the deep draught ships to ships of small size, light draught, and high speeds, and have come back in some of the lighter vessels to conditions approaching those under which Mr. Dudgeon worked, and have certainly obtained remarkable results. I had been asked to put these results in form for this meeting, but I had a feeling that it was possible for a member to make too frequent appearances before the Institution, and I thought, perhaps, that a little later on, at some other meeting of the Institution, I should have a better story to tell. Outside the Admiralty service, within the last year, we have managed to secure with twin-screws some very important results, which cannot fail to influence future practice; for I look on the trials of ships as a most useful form of "model experiment." In several ships which I designed and built when I was in the North of England, not exceeding 15 feet 6 inches in extreme draught, 225 to 250 feet in length, and 1,500 to 2,000 tons in displacement, we have obtained speeds of 19 knots on the measured mile, with the vessels fully laden. Anybody who knows what the law of "corresponding speeds" means, will understand that we have in the performances of those ships successfully overcome problems of as difficult a character in regard to fluid resistance and the utilisation of engine power as would have to be encountered in driving existing Atlantic steamers at speeds approaching 25 to 30 knots an hour. In these experiments we have had the most complete success—success not to be obtained, as I believe, with single screws. Mr. Holt has said, and I think he is correct in saying, that it is possible on the available draught of Atlantic steamers to get all that is necessary at present with a single screw. That is as regards propulsion only, but Mr. John has fairly put forward the case not merely from the side of propulsion, but also from that of safety against immense risks, and also in view of the probable increase of speed in future ships. Mr. Holt, of course, would be the first to admit that if higher and still higher speeds are reached, the available draught of water remaining practically a constant, that

which now holds good in vessels like the "Etruria" and "Umbria" would not continue to hold good. Without criticising the designs of those vessels, which I have not the least desire to do, I would add that what has not been proved is, whether a better result might not have been obtained in those vessels with twin-screws. That is a question which Mr. Holt has not dealt with, but he has simply shewn us that the vessels are grand performers as they stand, and I admit it most freely. There is one fact which has come to my knowledge recently in connection with an Italian twin-screw cruiser built on the Tyne, which I think may be of great interest to this Institution. She went across the Bay of Biscay on her voyage to Italy in very heavy weather—she was a very fine-lined ship carrying heavy guns far away towards the bow and stern—with all the conditions, therefore, for heavy pitching and scending. She was fitted with a governor in each engine-room, and I am informed, as a matter of fact, that those governors never worked all the way across the Bay; there was absolutely no indication of racing. It is for gentlemen here to say whether deeply immersed screws, such as she had, if fitted in Atlantic steamers, might not be a source of possible economy in working. I know that there are difficulties in the way of the introduction of twin-screws, but I know also that these difficulties are being considered with a view to their removal, by bringing the screws closer together and housing them better. I sincerely hope that all the thought, genius, and energy which are now being devoted to the question by Mr. John and other shipbuilders and shipowners will lead the travelling public to the possession of a class of vessels which will excel in speed and comfort; and which shall be, as regards their safety and sea-going qualities, superior to existing vessels. I believe that the use of twin-screws might help that on. There are many minor points in Mr. John's interesting and able Paper, but I have not time to deal with them. I should like to say one thing about the propulsion of twin-screw ships with one screw. I think that there Mr. John has overestimated the speed that might be expected to be obtained if one engine utterly broke down. I feel certain if a twin-screw merchant steamer were to be kept on her course at anything approaching the full speed possible with one screw at work, it would require rudder power such as no existing merchant steamer is ever supplied with. In the Navy trials are made of that nature, but the ships are fitted with very large rudders, because we there have to consider manœuvring powers. I will only make one remark, in conclusion, with regard to the increase of the beam of ships. Mr. John is well aware of this fact that a broad beamed stiff ship may roll but little. The "Inflexible" in the Navy has a metacentric height of 8½ feet. She went across the Bay of Biscay in very bad weather, and I think I am right in saying she never rolled more than twelve degrees. Breadth of beam is, in fact, often a source of steadiness, not in the strict sense of keeping the ship upright, but in the sense of diminished rolling. With the "Great Eastern" also, if I remember rightly the accounts of her voyages, there was not that excessive rolling which her great stiffness might have indicated. When something went wrong with her steering, and she fell off in the trough of the sea, of course there was heavy rolling. As Mr. John has pointed out, the breadth of beam, the stowage, and the metacentric height, all go to determine what the behaviour of a ship shall be.

Mr. G. A. Calvert (Member): My Lord, in the two interesting Papers which have been read this morning there is one point referred to—in both Papers more or less, and which has also been spoken of by Mr. White, that is the question of screw propellers. I think that is one of the elements in marine propulsion which has made less progress than any other branch of the subject. This cannot have been for want of experiment, because every ship has probably had two different propellers fitted in her lifetime. I think I am not saying too much in saying that very few engineers at the present day are able to state definitely, beforehand, what will be the performance

of a given propeller behind a given ship. Not only that, but even supposing the ship has been tried, I think few engineers would care to say that the propeller as fitted was the best propeller for that ship, and that no other propeller could be applied which would drive her half a knot faster. I venture to say that the principal reason why progress in the direction of the propeller has not been so marked as in other branches of physical science is because the matter has been treated and discussed, mathematically and experimentally, by models and by full sized trials, as a *whole;* whereas in other branches of science where marked progress has been made, matters have been treated in an *analytical* manner. For example, there have been cases where the propeller has had a foot knocked off the point of each blade, reducing it in diameter, and the ship has gone faster. Now, the whole of the conditions of that propeller were changed. To what ought we to attribute the improvement? Was it the reduced diameter, or the increased slip? Was it the increase in the number of revolutions, or was it the reduced mean pressure in the cylinders? Was it the reduction in the surface, or the modification in the shape of the blades? Or was it some one or more of those changed conditions that were beneficial and some one or more of them that were prejudicial? For, unless we know that, how are we to apply the experience gained in that case when dealing with other cases. What should we think of a civil engineer, who professed to design iron bridges, if we found that he had only the slightest knowledge of the direction and the intensity of the strains that come on the different parts of the bridge, if he only had a vague notion of the load it was intended to carry on the bridge, and if he did not even know the tensile strength of wrought iron, and that his practice was to copy other iron bridges which had stood satisfactorily? I am afraid we should not expect very great progress or development in bridge construction from his mode of dealing with the subject; probably we should not call it designing at all. Still, he might point to a dozen fine bridges as proofs of his skill. I think, with our present knowledge, there will always be an amount of guesswork in designing propellers, inadmissible in any other branch of engineering, and I must say it with all respect, because I can only speak of my own knowledge, there may be members of this Institution well able to design propellers with the same certainty of results as in other details of engineering design; but I think if we were able to put our hands on one part of a blade and say: "This square foot is contributing so much towards the thrust, and is absorbing so much of the horse-power, whilst this other square foot is contributing more thrust and absorbing less horse-power," I think, then, we should be in a position to begin to trace out the principles which should govern the design of a screw propeller. I believe that such a method of analysis is not only possible but easy; and, acting on that belief, I have, for the last eight or nine months, been experimenting with an apparatus which I devised for the purpose of ascertaining various facts with regard to the motion of bodies passing through water. There have been experiments made, I am speaking now of published experiments, on the resistance of variously shaped bodies passing end-on through water, on surface friction, and, to a limited extent, on the resistance of *planes* moving obliquely through water; but I have not been able to come across any records of experiments made to ascertain the resistance of bodies shaped like the sections of a propeller blade passing through water at different angles and at different velocities, and the resulting thrust in a fore and aft direction, such as a propeller blade contributes to the propulsion of the ship. These are the points which I have been trying to investigate. Another point is the relative efficiency of thick and thin blades, and of the way that the thickness is disposed; I believe it is quite possible to design two propellers, which would be of the same diameter, the same pitch, the same shape, surface, and thickness of blade, yet, by differently disposing the thickness, you might in one case absorb twice the horse-power required in the other case to obtain the same speed of vessel. Then there is another point which has not been investigated, that is the

speed of the water in different parts of the wake of a vessel. Until we know the condition of the water in which the propeller is working we are not likely to make any decided advance. There is just another matter which I think it is necessary should be investigated before we can go from the model propeller to the full-sized propeller, and that is the law which governs the increase of thrust with the increase of breadth of blade which, I think, is not generally known. I see the time is going on, and I do not think I am justified in detaining the meeting longer now, but, if circumstances permit, I hope at some future time to explain fully what I am doing in the direction I have indicated.

Mr. W. H. White: My Lord, might I be permitted to say that I for one should be extremely sorry for this meeting to terminate with the impression that the speaker's range of reading represents what has been done in this matter of experiment with the screw propeller, or the motion of the water in the wake of a ship. I am afraid that the contents of our own "Transactions" have not been quite mastered, because the Messrs. Froude, both father and son, have been working for years in this very direction.

The President: Gentlemen, with your permission, I will now ask you to adjourn, and this discussion will be resumed to-morrow morning.

FRIDAY, 30th JULY, 1886.

Mr. G. A. Calvert: I rise to make a personal explanation. Mr. White said, at the conclusion of yesterday's meeting, that Mr. Froude had taken up the investigation of propellers in precisely the same way that I had described, or rather hinted at, in my remarks. Now, I think there must have been some misunderstanding, for I have it on what I consider the best authority, that of Mr. Froude himself, that he had not done so. After Mr. Froude read his paper at the London meeting in April last, I wrote to him, and explained briefly what I was doing, adding that if he were working in the same direction, I should not proceed further in the matter. Mr. Froude replied, saying that no doubt the investigation of the forces on obliquely moving planes should be the basis of investigation of propellers, that he and his father had always looked forward to making such experiments, but that the opportunity had never offered itself.

Mr. F. P. Purvis (Member): In this Paper, my Lord, the question of speed is necessarily one of the most important. This is so for two reasons; first, that after a ship is built the expected speed has to be obtained, and second, that at the very outset of a design the dimensions of a ship have to be regulated by the speed that is fixed upon. In some work upon which the firm I have the honour to be connected with were engaged for a very high speed boat, we found that the dimensions finally had to be fixed, not even by what was best suited to obtain a certain speed, but by what was absolutely necessary to put in the boilers to get the power to obtain that speed. For these reasons the speed question is a most important one. Mr. John gives a formula that he finds useful. I might ask him if it has a scientific basis, but I suppose he will say that it has not, that it is an empirical formula, and that he uses it because he finds it fits in practical instances. So far as I can see, the formula does not satisfy the piece of very sound advice that your lordship gave to this Institution some years ago in the discussion on a paper by Mr. R. E. Froude, in which great attention had been called to the variation of power with speed, and in which it was shown that at some speeds a small increase requires

a very large increase of power, while at other speeds a small increase is obtained by a comparatively small increase of power. A word used largely on that occasion was the word "humps," and your Lordship gave the advice that engineers should study the importance of humps. I do not know that it is possible to study humps very thoroughly without the aid of an experimental tank; but one thing generally known is that the speed at which humps occur is approximately the same provided the length of the ship is the same; that in two ships, having the same length, even though they differ in fineness, the hump speeds are not very different. The intensity of the humps depends upon the fineness or fulness, so that although at such speeds a fine and a full ship would both require a great increase of power for additional speed, still the fine ship would require less increase than the full ship. Mr. John's formula quite ignores this, for he compares two ships that are very different in length, and compares them at the same speed. If he wanted to get something to carry out your Lordship's suggestion he would have to compare them, not at the same speed but at different speeds. Mr. John takes the comparison up to sixteen knots. If he were to carry it up to twenty, or twenty-one, or twenty-two knots the comparison would be a good deal vitiated.

The President: You will allow me to interpose for one moment. Do not suppose any remark of mine was calculated or intended to instruct such a man as Mr. John.

Mr. Purvis: I think your Lordship's suggestion was a very sound one. The matter of strength is one of very great importance. Perhaps Mr. John will allow me to ask him, in giving these figures of six or six and a half tons per square inch, what dimensions of wave have been assumed, and also whether credit has been taken for the strength given to the ship by the addition of the wooden decks. In order to get anything like comparisons we must have those two points before us. Mr. John says a good deal about twin-screw propellers, and the advantage to be obtained by fitting twin-screws in Atlantic liners. Since the time to which Mr. John refers there have been a good many additions to the Government ships fitted with twin-screws. I might remind the meeting, I am afraid I do not remember the figures, but I might remind the meeting of the immense success obtained by H.M.S. "Phæton," built and engined by Messrs. Robert Napier and Son. The performances came out remarkably good, and if they are confirmed by the results of other ships twin-screws will come to take their place on account of the great efficiency that is to be obtained from them. Apart from any other consideration I think Mr. John makes a very good case in what he says for sub-division in twin-screw vessels. Perhaps Mr. John would allow me to reply to one or two of Mr. Holt's suggestions. The effect of the middle line bulkhead would be, as Professor Elgar told us the day before, with regard to putting in shifting boards, to diminish the effect of loose water to one-fourth. If one side of the ship is bilged, water can be let into the other, so getting rid of Mr. Holt's objection, and at the same time diminishing the effect of the loose water to one-fourth of what it would be if there were no middle line bulkhead.

Mr. J. H. Biles (Member): My Lord, as the remark that Mr. Purvis has quoted from your speech was made in connection with a Paper of mine, I am very pleased to hear Mr. Purvis give us so much valuable information on this question of humps. Though I quite agree with his criticisms of Mr. John's formula, I think the purpose Mr. John had in view is more than fulfilled by putting it in the form in which he does. As to approximate empirical comparisons. These empirical comparisons are very useful when the whole conditions on which they are based are thoroughly understood; and though they are not absolutely scientific and not absolutely accurate, they serve the purpose for which they are intended. I have had some little experience in connection with designing Atlantic passenger steamers and in most of the points which Mr. John predicts as being the direction in which future progress will

be made I quite agree with him. On the question of twin-screws there are many advantages which accrue almost incidentally. In the first place, I think, account is not fully taken of the fact that when a twin-screw ship is being handled in dock, though there is more liability to damage the propellers when the vessel comes in contact with the quay, yet there is far less liability of the vessel coming in contact with the quay walls on account of the greater manœuvring power. And if it is decided to have twin-screws, I think it will not be difficult to devise barges which will fit over the screws of the vessel when she comes into port, and which will effectually protect her from any possibility of injury. There is another advantage which, I think, is perhaps one cause of the increased efficiency of twin-screws, and that is the fact that you would necessarily have smaller engines. You necessarily have smaller propellers, and you may run them at a higher speed. I think the researches of Mr. Froude show that small propellers run at a high speed are more efficient than larger propellers run at a slower speed, and for that reason I think it is very likely that as great an advantage will follow from the use of twin-screws in merchant steamers as has already followed their adoption in war vessels. There is also a further advantage, namely, that you get lighter machinery; and a still further advantage in the less liability to bad castings and forgings in smaller engines. And when you get to the question of high speed and a big power, say twenty thousand horse-power, that is no small advantage in favour of twin-screws. With respect to the question of a middle-line bulkhead, I am very sorry to say I cannot quite agree with Mr. John as to the advantage of such a bulkhead in a big passenger steamer. It seems so me that if you are dealing with the question of sub-division only as a protection against sinking, in case of damage, the middle-line bulkhead is a very serious disadvantage. If you get in a lot of water and have a perfectly water-tight middle-lined bulkhead, you may be worse off than if you hadn't it, because you get such a list on the ship that it becomes difficult to handle her, to lower boats, to move about her deck, or to do anything of that kind; passengers are more likely to be panic stricken on a ship with a big list. But, I think, that increased sub-division in a longitudinal direction is almost absolutely necessary if an immunity from sinking is to be laid down as a principle in the construction of future Atlantic steamers. I think a longitudinal sub-division should take place, not at the middle line, but nearer the sides of the ship; and we should recognize the fact that where you have boilers and engines in different compartments you must necessarily have the doors of those compartments open, so that it is desirable to arrange to keep your ship afloat quite easily, even supposing there is no possibility of shutting the doors. I think the proper way to arrive at that is to have a ship of great beam and great depth and to have two longitudinal bulkheads extending to the upper deck at a considerable distance from the sides of the ship to sub-divide the space between these longitudinal bulkheads and the sides of the ship as completely as possible, so as to divide it both under and above water; so that supposing you get the side of the ship and the longitudinal bulkhead both perforated on one side, and the water gets into the centre of the vessel, you have still enough buoyancy left in the minutely sub-divided portions between these wing bulkheads, the side, and the upper deck to keep the ship afloat. I think it is not difficult if you accept the position of giving, say sixty-four or sixty-five feet of beam to make a ship in which you can have the coal stowage arranged so that you can work it with the greatest possible facility, and, at the same time, have the ship arranged so that if she were left with a hole in her side and in her wing bulkhead it would be impossible for that ship either to take a considerable list or to sink. I think, probably, I do not differ from Mr. John quite so much as appears, but that I am going a little further; and, instead of having one longitudinal bulkhead, I think it would be much better to have two. Of course, broad ships, as Mr. John has pointed out, must necessarily mean deep ships in order to have anything like comfort at sea. Then you are limited as to the length by the consideration of the first cost and of

the number of passengers you wish to carry. I think the experience of a ship like the "America," only four hundred and thirty feet long, has shown that it is not necessary to go to five hundred or five hundred and fifty feet with Atlantic steamers in order to get high speed. I think a vessel four hundred and thirty feet in length, with sixty-four or sixty-five feet of beam, and forty-five feet in depth is about the best form of steamer for the Atlantic passenger trade. I have roughed out a design based on the most recent improvements in marine engineering, because it is on these that progress in ship designing for the Atlantic passenger trade depends; and I think it would be quite possible to build a vessel of a special construction of about seven thousand tons gross register, which would steam twenty-two knots per hour across the Atlantic with a less consumption of coal than the "Umbria" and "Etruria" have at present. This speed would enable her to cross from Liverpool to New York in six days, or from Queenstown in five and a half days. I think that is likely to be the vessel of the future, and that vessel, I am sure, would be, commercially, quite as successful as the "Umbria" and "Etruria."

Mr. J. Jennings Campbell (Visitor): My Lord and Gentlemen, in Mr. John's remarks on page 148, in reference to the propelling machinery of ships for the Transatlantic passenger service, he has alluded to the fact that, up to the present, the great lines have been rather behind than ahead of the times with regard to the type of engines employed. And that while other lines of steamers have started triple expansion engines for some years, at the present time the great Atlantic liners have only the ordinary compound, or double expansion engines. Having, however, neglected to take up triple expansion engines at the right time, I think it would be a great mistake for these companies to have them fitted now, as I am strongly convinced that the quadruple expansion engine will far more rapidly supersede the triple expansion than the latter did the ordinary compound. Owners of Atlantic liners should, therefore, go a step further at once and adopt quadruple expansion engines, and I would strongly urge their being fitted to the next American liners built. Engines of this type are being made very successfully, and we have recently read in "Engineering" of a set of quadruple expansion engines which worked on a trial trip (whatever the value of that may be) with a consumption of only $1\frac{1}{8}$ lb. of coal per I.H.P. per hour; and although the sea consumption might be more than this, yet with properly proportioned quadruple expansion engines it ought not to be more than $1\frac{1}{4}$ pounds. I should very much like to point out the type of engine I should recommend for this purpose, if I am in order in doing so at this discussion. The engine I should recommend would be a three-crank six-cylinder engine similar to that of the "City of Rome," or the "Normandie," only with the small cylinders reduced in proportion to the large, and worked on quadruple expansion as follows: The steam from the boilers would only be admitted into one of the small cylinders, thence expanding into the two others from which it would pass into one of the large cylinders and finally expand into the other two. I am not certain who is the originator of this arrangement. Some time ago I thought that I was, but I afterwards discovered I was mistaken. I find, however, that it possesses some very valuable properties, for by its means a large measure of expansion can be obtained with small cylinder ratios, allowing the cut off in all the cylinders to take place at such points as will cause the expansion to begin in one stage at the same pressure at which it finished in the previous one; without necessitating a cut off much earlier than half-stroke in any one case. For instance, with a sixteen-fold total expansion the small cylinders need only to be one-fourth the capacity of the large ones, and as two small cylinders deliver into one large one; the cylinder ratio at each stage of the expansion would be only 2 : 1. And if the steam were cut off at half stroke in all the cylinders, the pressure at the point of cut off in the intermediate and low-pressure cylinders would be equal to the terminal pressure

in the preceding cylinders; thus avoiding all "drop" and obtaining the greatest possible efficiency. This form of engine has also great advantages for working in different ways, such as triple expansion, or ordinary compound, in the event of a break-down, and the three cylinders of each size being alike in every respect, the engine should be a cheap one to make, while the spare gear would be reduced to a minimum. I think, in fact, that for all reasons this is the best type of engine for large powers; especially where, as in the Transatlantic passenger service, the machinery is always working at full power.

Mr. James Hamilton, junr. (Member): My Lord and Gentlemen, I would rather listen to the shipowners of Liverpool giving their views upon some of the important points Mr. John has brought forward, upon twin-screws, central bulkheads, and the advisability of building purely passenger steamers, and such points as Mr. Holt referred to. But as the discussion has taken this form, I should like to say with reference to Mr. John's formula that I think it is open to objection, as I believe he will admit, and for this reason—that it perpetuates the old fallacy which belongs to the Admiralty formula, that the power follows the law of the cubes. Of course, at medium speed, the power generally does follow the law of the cubes; but at maximum speeds, which are those in regard to which we have any real difficulty in predicting the power, it very seldom indeed follows this law, as Mr. John is well aware. There, it oftener is the fourth or fifth power. I think that is an objection. I have tried, myself, to take speed out of the question altogether, and arrive at a prediction of power by two steps instead of by one. But whether the other part of the formula, if divorced from the speed factor will be useful I cannot say, as I have had no opportunity of applying it; but I think there is one thing against it. Mr. John spoke of the constants corresponding, in the case of the "City of Rome" and the "Normandie," two ships of very different size, at the same speed. I think that is rather against the formula than otherwise. It would be more in its favour if they agreed at corresponding speeds, and not at the same speed. Mr. Purvis referred incidentally to the great speed we had got with H.M. "Phæton," the Admiralty cruiser; but still, although that was true, and with all due deference to Mr. White, who said yesterday that he believed the great results got recently were due to twin-screws, I do not think we can say that it has been absolutely demonstrated that, for merchant steamers, at least, better efficiency can be got out of twin-screws than single screws. We ourselves have done a great deal in the way of designing and advocating twin-screws for Atlantic steamers, but more on the score of the additional safety and reduced tendency to racing, to be got out of them. Mr. John has taken a great deal of trouble to be accurate historically, and I am sure he will not object to my referring to one little minor point, as he thinks it worthy of a place in his Paper. He says that the "Servia" was the first Atlantic steamer which had a double bottom on the bracket system. I may tell Mr. John that the "Parisian" was commenced before the "Servia," and finished before her, and that she had a bottom on this principle. I can see how the mistake arises, because Mr. John will naturally go back to the source of information he has been familiar with, at White Lion Court; but I am sure he won't object to my saying that some of the ships of best repute sailing out of Liverpool, the "Parisian" amongst the number, are not classed ships, being considered superior to classed ships.

Mr. E. A. Linnington (Member): My Lord, I would like to remind the Institution that at the meeting last year I read a Paper on the "Propelling Machinery of High Speed Ships," in which particular attention was given to the question of applying twin-screws to these deep draught, high-speed Atlantic liners, and therein I endeavoured to shew that if we were to have any further increase of speed it appeared desirable that twin-screws should be adopted, even on the question of propulsive

efficiency. It is well known that many years ago Mr. White reviewed the whole question of applying twin-screws to merchant ships; and also that in a particular class of ships—the deep draught iron-clads—he conclusively proved that a very large advantage in propulsive efficiency existed with the twin-screws. Since those days, the propulsive coefficient with twin-screws has been raised considerably, not in a haphazard manner, but by continuous and patient improvement; and it is highly probable that even now the best results, that is to say ultimate results, have not been secured. On page 158 and in Table IV. of this Paper there is a very curious thing, and that is a rule in print for screw propellers. In that rule I recognize an old friend; and it may be interesting to the meeting to know that in substance it is to be found in the "Transactions" for 1878, in Mr. Froude's analysis of the action of the screw propeller, where it was shewn that under certain conditions the blade area varies as resistance divided by the square of the speed; that is the same thing as effective power divided by the cube of the speed; and if we assume the effective horse-power to be proportional to the indicated horse-power, we have practically the same formula as Mr. John has given us here. Now, soon after Mr. Froude gave his analysis to the world, I endeavoured to see how this formula would apply in practice, and found that for similar screws similarly placed upon similar ships a *constant* could be used, but that with any departure from any one of these numerous similarities we were all at sea. Mr. John has taken not the blade area, but the disc area, whereas the difficulty with screw propellers is not so much to determine the disc, as having got the disc to know what to do in it. Mr. John has called attention to the protection required by the twin-screws when coming alongside quays or going into dock. Perhaps I may be allowed to say that on H.M.S. "Polyphemus" a very simple above-water protector has been fitted, which would probably be found quite sufficient to protect the screws of any ship coming alongside a quay or going into dock. In the "Polyphemus" the screws are very much exposed indeed, as the ship is very fine at the stern. There appears to be some agreement of opinion that if the future Atlantic vessels are to have higher speeds than the existing ships, it is desirable that cargo should be given up altogether and only passengers be carried. If the ships are to be entirely passenger ships, there is really more reason why they should have reliable propelling apparatus than if they carried a smaller number of passengers; and the duplication of machinery does make the propelling power more reliable; and I think if a ship fitted with twin-screws were to be put before the travelling public she would receive a very large amount of patronage. Without entering upon the general question of fitting middle-line bulkheads, I may observe that if twin-screws are adopted there is a very great necessity for a middle-line bulkhead in the engine-room, so that the full advantage of duplicated machinery may be obtained under any circumstances. In the boiler-room this bulkhead would upset the compact arrangement with three boilers abreast adopted in the recent high-power ships. In concluding these few remarks I would like to draw attention to a matter not only of professional interest, but really of national concern, and that is if any of these ships should at any time come into the service of the State as armed cruisers their value upon such a service would be very much enhanced if they were provided with duplicated machinery. These few remarks may appear somewhat disjointed, but I trust they will not be considered out of place in connection with this important Paper.

Mr. B. Martell (Member of Council): I would much rather listen to gentlemen like Mr. Holt, who has had so much experience upon a great subject of this kind, than offer any remarks of my own; and I should have said nothing if Mr. Hamilton had not called me to my legs. He has corrected Mr. John, or tried to do so, on a historical part of his paper. Now I want to correct Mr. Hamilton. Mr. Hamilton takes credit for introducing that system of double bottom in the "Parisian."

Mr. Hamilton: No, no.

Mr. Martell: Excuse me, did you not say that the "Parisian" was the first steamer?

Mr. Hamilton: The first Atlantic steamer.

Mr. Martell: I now refer to the "Buenos Ayrian," built by Messrs. W. Denny & Brothers. Almost immediately after I had the honour of reading a Paper at Glasgow shewing the system of construction of double bottoms. That was the first vessel engaged in the Atlantic trade in which was introduced that system of cellular bottom. The question of twin-screws has been alluded to particularly, and no doubt it is a very important question; and, when we get data sufficient to guide us in the matter, I have no doubt in my own mind that for ships of great power it is a system that will be generally adopted. But up to the present time we have not got that data. There is a fleet of ships called the Hill Line, and some of you, gentlemen, will know those vessels; but I do not know that these ships have produced very extraordinary results with their twin-screws, and I rather question whether they have been such a commercial success from all I have heard with regard to the adoption of twin-screws. Therefore, I say that so far as our experience goes of twin-screws in commercial ships up to the present time, I do not think we have a very great deal of practical knowledge on the subject such as would induce owners to adopt that system in preference to that of the single screw. But there is no doubt that if you are going to build ships in which you exercise fifteen thousand horse-power, as you do in the case of the "Etruria," it will be very necessary that you should divide that power, and instead of applying it all through one screw should divide it into twin-screws, both for purposes of economy and additional safety. But what we particularly want for guidance is additional data.

Admiral Sir John Hay (Vice-President): I will not detain the meeting long, but something which fell from Mr. Linnington induces me to say a word or two upon the subject of twin-screws as applied to ocean-going steamers, which may be employed for Imperial defence. It is quite certain, it seems to me, that our extended commerce will always require our Navy proper to be assisted by vessels such as the "Oregon" and other ships, which have been used for that purpose on a recent occasion. I believe it is quite certain that for war purposes the twin-screw is recognised by all naval men as having very many advantages. If that be so, as I believe it to be, it is quite evident that it would be a great advantage under such conditions as occurred at the loss of the "Oregon," if the compartments could be made completely water-tight; and the twin-screw gives the power of separating the ship longitudinally; if the longitudinal bulkhead is made perfectly water-tight it gives the very greatest possible protection. There is no reason why there should not be additional transverse compartments; wherever necessary and convenient—and it seems to me that it is not necessary that there should be free passage through the bilge, but that the various engines and boilers should be separated, so that at the time of collision, or in the event of any hole being made in the ship's side, the fires may not be put out, and that some of the engines may be maintained so that they could assist in clearing by pumping those portions of the ship which have been invaded by the water. A separate pump being fitted in each compartment. It seems to me that the advantage is so manifest that there should be a hermetically closed water-tight bulkhead, running fore and aft, for war purposes, that I trust the objections to it for passenger steamers may be overcome, as well as the suggestion, which I think Mr. John made, that the artistic beauty of the saloon would be very much marred by this sub-division. But, be that as it may, it seems to me that you cannot trust to bulkheads which are only closed occasionally by doors. In the loss of the "Vanguard," in order to prevent the coal dust getting into the groove in which the door ran, a wooden batten was fixed, and it was found, that at the moment it was wanted to close

the door, they could not get out the wooden batten. Something of the same kind occurred in the loss of the "Grosser Kurfürst;" and with regard to the "Oregon," there was some little difficulty in closing the compartments. What is required for war purposes is entire and complete isolation of the different parts of the ships, and the closing of communication between them. Of course, I am not a naval architect; but it seems to me that each of these compartments should be provided with pumps of their own, that there should be no communication open either into the bilges or in any other way, but that each separate compartment should be closed, so that it may be completely isolated and cut off. I know how short the time is, but I want to say, looking at it from a naval and Imperial point of view, that the safety of these ships will be greatly enhanced by the adoption of completely manageable bulkheads, and the use of twin-screws; and I trust that those who travel in the ships will recognize the additional safety given to passengers by that method of construction.

Mr. W. John (Member of Council): My Lord and Gentlemen, I do not think I need detain the meeting more than a minute or two. I am extremely flattered and pleased by the way, far beyond its merits, in which my paper was received, and with the discussion the subject has received, a discussion due to its great importance. I am pleased to find gentlemen like Sir John Hay and all who have spoken here, more or less, have faith in the future of the twin-screw and sub-division. (Hear, hear.) I think safety is a matter in which the public have a right to greater consideration than they have at the present time on the Atlantic; or that they can possibly have with the single-screw ship, and I am perfectly certain that twin-screws are coming, and coming in the near future. Mr. Holt and other speakers alluded to the danger of water getting in at one side of the middle-line bulkhead and giving the ship a heel; but I think Sir John Hay replied to that very well, because if the ship gets heeled over by water coming in at one side it cannot get across the ship, and the ship cannot be capsized. The water is well down in the bottom of the vessel, and she may get a large heel, but she cannot be capsized, and you have your fires on the other side well out of the water, and you can both pump the water out, and also steam a-head. When Mr. Hamilton spoke of my remark about the "Servia," I remembered at once the "Parisian," and that I had forgotten the "Parisian" in writing my paper. I had also forgotten the "Buenos Ayrian," for while trying to be as accurate as possible in a historical review, you cannot always bear everything in mind. Mr. White mentioned yesterday about the metacentric height of the "Great Eastern," and referred very properly to the fact that great metacentric height does not necessarily lead to heavy rolling. That is so; but there is an intermediate stage; and I would put the illustration in this way: In the earlier days of our ironclad ships they were heavy rollers, and it was said this was so on account of the amount of armour plates and top weight. As a matter of fact they were heavy rollers because the weight was too low in them. They had too much stability. The efforts of Naval constructors were for some years to come down in metacentric height for the purpose of getting steadier ships. In the merchant service, ships were still lower in metacentric height than in ships of the Royal Navy, and for this reason, that a ship of war has practically her guns, her armour, and her heavy weights chiefly above water, and has practically the heavier side uppermost, while in the merchant or passenger ship the weights are below and the upper parts are much lighter, or she is in the position of a vessel floating with the heavy side downwards. Therefore the merchant ship can afford to be of a smaller metacentric height than they dare go in the Admiralty service. In the case of the "Great Eastern," I think it was at the first year's meeting of the Institution twenty-six years ago that Mr. Froude discussed the question of the stability of that vessel. He showed that if the "Great Eastern" had had one-half of the stability she has got she would have had such a lengthened period of rolling that she could never have got into synchronism

with any of the waves of the Atlantic. Her period would have been very much longer, and she would have been a very much steadier ship. Something of the same kind occurred in the case of the "Devastation," where her period of rolling is very extended. I think it was Mr. Campbell who mentioned something about quadruple engines. I can only say that I think our Company put afloat the first set of quadruple engines at the present time, and that it has been running now for a couple of years carrying one hundred and sixty-four pounds pressure of steam. I need not discuss the formula. I did not put it forward as a scientific matter but as an empirical thing that we have found serviceable in our drawing office, and I thought many people here would be glad to hear of it. I can only thank you for the kind reception you have given to my Paper.

The President: Gentlemen, I am sure you all desire that I should convey to Mr. John your united thanks for his most interesting Paper; and let me on your behalf congratulate him upon the able and practical and useful discussion that has ensued upon it. Time is pressing, and I will ask you merely to allow me to return him your thanks. [The President then invited the Mayor of Liverpool to take a seat upon the platform.] I am quite sure every man here, and almost every man elsewhere will agree with me that we cannot allow this most agreeable, most instructive, and most successful meeting, which will be engraved upon our memories for the rest of our lives, to close without returning hearty thanks to the Mayor of Liverpool for his reception and his treatment of us during our stay here. This is a subject upon which I could dwell for a considerable time with gratification to myself, but time is not at our disposal. I will convey to the Mayor, with your permission, our united thanks; the thanks not only of us who are strangers to Liverpool, but also of those who are inhabitants of Liverpool, for the courtesy and kindness and liberality and the success which has attended his efforts to provide for our instruction, our comfort and our amusement. (Prolonged cheering.)

The Mayor of Liverpool: My Lord and Gentlemen, I thank you for having passed this vote of thanks to me in so hearty a way I am sure it affords me, in common with the other citizens of Liverpool, great pleasure to have welcomed the Institution of Naval Architects; and I feel sure that your visit here has been a very happy and a very pleasing one, and that we feel very much indebted to you for coming amongst us. It gives us the opportunity of showing to you what this great City is possessed of, and also of showing you that we are playing a very considerable part in connection with our Empire in maintaining, as far as we possibly can, the prestige of our commerce and of our civil institutions. I sincerely hope this will not be the last time we shall have the distinguished honour of receiving the Members of the Institution of Naval Architects.

PRELIMINARY PROCEEDINGS.

Friday Morning, July 30th, 1886.

The following gentlemen (having been duly recommended by the Council) were unanimously elected members of the Institution:—Mr. Alfred Alchin, Superintendent Engineer, Messrs. Watts, Ward & Co., Liverpool; Mr. Johan H. Beucker Andreœ, Chief Inspector of Machinery, Dutch Navy, The Hague, Holland; Mr. Robert Armstrong, Managing Engineer, Messrs. Mordey, Carney & Co., Dry Docks, Newport; Mr. James Bain, Superintendent Engineer, Messrs. Cunard & Co., Liverpool; Mr. Asplan Beldam, Consulting Engineer and Naval Architect, London; Mr. Peter Blair Black, Naval Architect, London; Mr. Charles Blagburn, partner in the firm of Messrs. Menzies and Blackburn, Consulting and Marine Engineers, London; Mr. Andrew Browne, Superintendent Engineer, Pacific Steam Navigation Company, Liverpool; Mr. William Bruce, Marine Engineer, Liverpool; Mr. George R. Clover, partner in the firm of Messrs. Clover, Clayton & Co., Woodside Graving Docks, Birkenhead; Mr. Charles Broadfoot Connell, Shipbuilder, Partick, Glasgow; Mr. James Murray Croom, Manager, Engine Works, Messrs. Earle's Shipbuilding and Engineering Company, Hull; Mr. Thomas Downie, Manager, Messrs. H. and C. Grayson, Liverpool; Mr. John Gibb Dunlop, Superintendent Engineer, Orient Steam Navigation Company, London; Mr. Alexander Elder, Managing Director to the British and African Steam Navigation Company, Liverpool; Mr. William Esplan, Marine Engineer and Naval Architect, Liverpool; Mr. Andrew Gibb, Manager and Consulting Engineer to Messrs. Rait and Gardiner, London; Mr. William Glover, Consulting Engineer and Naval Architect, Liverpool; Mr. Farrant Good, Consulting Engineer, Messrs. Morel Brothers, Cardiff; Mr. John Gravell, Surveyor, Bureau Veritas, Newcastle on Tyne; Mr. Joseph Grundy, Assistant Superintendent Engineer, Messrs. W. Johnston & Co., Liverpool; Mr. James Findlay Guild, Consulting Engineer and Steamship Surveyor, Dundee; Mr. Arthur Charles Hay, Superintendent to Mr. Joseph Hoult, Shipowner, Liverpool; Mr. Alfred Holt, Managing Director, Ocean Steamship Company, Liverpool; Mr. Andrew Horn, Manager, Waterford Steamship Company, Waterford; Mr. Stewart Gordon Horsburgh, Superintendent Engineer, White Star Line, Liverpool; Mr. John Griffith Hughes, Superintendent Engineer, the Guion Line, Liverpool; Mr. James Laing junior, partner in the firm of Messrs. J. Laing and Co.. Sunderland; Mr. Charles Jones, head of the firm of Messrs. J. Jones and Sons, Liverpool; Mr. James Gordon Lyon, Manager, Deus Ironworks, Arbroath; Mr. Andrew Maclean, Managing partner, Messrs. Barclay, Curle & Co., Shipbuilders, Partick, Glasgow; Mr. George Frederick Mason, Manager, Canada Works, Engineering and Shipbuilding Co., Birkenhead; Mr. Alfred Morcom, partner in the firm of Messrs. Belliss & Co., Engineers, Birmingham; Mr. Frank H. Pearson, Assistant General Manager, Messrs. Earle's Shipbuilding and Engineering Co., Hull; Mr. Walter Phillips, Superintendent Engineer, the Monarch Line, London; William C. Roberts, Superintendent Engineer, the Glen Line, London; Mr. David Rollo, partner in the firm of Messrs. J. Rollo and Sons, Liverpool; Mr. Charles Theophilus Ramsay, Superintendent Engineer to the Beaver and Star Lines of Steamers, Liverpool; Mr. Thomas Bland Royden, M.P., partner in the firm of Messrs. Thomas Royden and Sons, Liverpool; Mr. Douglas Stone, Manager to Messrs. R. Stone, Ship and Yacht Builders, Erith; Signor Carlo Vigna, Inspector de Genie Maritime Ministero della Marina, Rome; Mr. William Wallace, General Superintendent Allan Line Engine Works, Liverpool; Mr. Tom Dodd Widdas, Surveyor, Bureau Veritas, Liverpool; Mr. Gustav William Wolff, partner in the firm of Messrs. Harland and Wolff, Shipbuilders, Belfast; and Mr. John Yeo, Instructor in Steam, Royal Naval College, Greenwich.

The following gentlemen were elected Associates:—Mr. Samuel Lee Bapty, Mr. Cuthbert Arthur Brereton, Mr. Lindsay Burnet, Mr. Edward A. Cohan, Mr. Arthur Cohen, Q.C., M.P.; Mr. John Dempster, Admiral C. C. Dent, Mr. Richard le Doux, Mr. Charles Elms, Sir Gerald Fitzgerald, K.C.M.G.; Mr. John Sacheverell Gisborne, Mr. W. S. Graves, Mr. John Henry Harris, Mr. James Malcolm Hay, Mr. W. Becket Hill, Mr. Petronius Hodges, Captain Swinton Colthurst Holland, R.N.; the Honourable Charles Archibald Hope, Mr. S. D. Hornby, Mr. E. Inman, Mr. Thomas H. Ismay, Mr. Donald Kennedy, J.P.; Captain J. M. Lagerwall, Vice-Admiral J. Likhatchof, I.R.N.; Mr. G. Fosbery Lyster, Mr, C. Mac Iver, Mr. Henry Mac Iver, Mr. Gordon Miller, Mr. William Palmer, Mr. William Thomas Pover, Mr. George Ratliffe, Mr. James Spence, Mr. W. Watson, Mr. F. W. Webb, and Mr. James Williamson.

PROCEEDINGS IN LONDON.

INSTITUTION OF NAVAL ARCHITECTS.

MARCH 30 AND 31, AND APRIL 1, 1887.

INTRODUCTORY PROCEEDINGS.

The Meetings of this, the Twenty-eighth Session of the Institution of Naval Architects, were held on the 30th and 31st March and 1st April, 1887, in the Hall of the Society of Arts, John Street, Adelphi.

The opening Meeting was presided over by the Right Hon. the Earl of Ravensworth, President of the Institution, who commenced the proceedings by calling upon the Secretary, Mr. George Holmes, to read the Report of the Council, which was as follows:—

REPORT OF COUNCIL, 1887.

The Council is glad to be able to report that the Institution continues to make satisfactory progress. During the year which has just elapsed, one hundred and forty-eight new members and associates were elected, which is equivalent to an increase of members of about twenty-five per cent. in a single year. The condition of the finances, as will be seen from the annexed statement of receipts and expenditure, reflects the general condition of the Institution's prosperity.

The above-mentioned abnormal increase in the number of members was due principally to special circumstances. In June last the Council received a most cordial letter from Sir David Radcliffe, the Mayor of Liverpool, inviting the Institution to hold a Summer Meeting in that city during the last week in July. The invitation was accepted; and the second Summer Meeting held by the Institution proved a signal success. Nothing could have exceeded the kindness and the public and private hospitality of the Mayor and citizens of Liverpool to the members who attended the meeting. Five papers of marked scientific value were read and discussed, and will be published in the forthcoming volume of the Transactions; also interesting excursions were made to inspect the Docks, the Crewe Locomotive Works, Messrs. Laird's Shipbuilding Establishment, Messrs. Cope's Works, and the Atlantic steamships the *Germanic* and the *Etruria*. This Summer Meeting was the principal cause of the large increase in the numbers of the Institution, no less than forty-five members and thirty-eight associates having been elected on that occasion.

The Council announces with much pleasure that it has just received a most kind invitation from Mr. W. T. Doxford, the President of the North-East Coast Institution of Engineers and Shipbuilders, and from the Mayors and Corporations of Newcastle-on-Tyne and Sunderland, to hold a Summer Meeting this year at Newcastle-on-Tyne and Sunderland. The invitation has been accepted, and the Meetings, of which particulars will in due course be announced, will take place at the end of July. The Council confidently anticipates that its action in accepting the invitation will commend itself to the members, and that the Meetings will be attended with the same excellent results to the Institution which followed the Glasgow Meeting in 1877, and the late Summer Meeting held in Liverpool.

The Council deeply regrets having to announce the death, within the last few days, of one of its colleagues, Mr. William Denny, of Dumbarton. Mr. Denny's services to the Institution, and to the cause of scientific naval architecture and education, are well known to all who have taken part in the Meetings, and his loss is greatly felt and sincerely regretted.

In conclusion, the Council congratulates the Institution upon the great interest taken in its proceedings, and the marked scientific activity displayed by the members during the past year, no less than twenty-three papers having been read, many of which were of great importance, while several others were offered for the Summer Meeting, but had to be declined on account of the limited time available for discussion.

Institution of Naval Architects.

Statement of Income and Expenditure for the Year 1886.

Dr.

1885.	£	s.	d.	£	s.	d.
Dec. 30. To Balance :—						
In Treasurer's hands	763	17	3			
In Secretary's hands	55	9	6			
				819	6	9
1886.						
Dec. 31. Annual Subscriptions				1,511	11	5
Sales of Volumes				140	6	5
Admiralty Grant				250	0	0
				£2,721	4	7

Cr.

1886.	£	s.	d.	£	s.	d.
Dec. 31. By Cash paid :—						
Rent of Rooms				200	0	0
Cleaning Rooms				37	14	0
Attendance and Expenses at Meetings				16	12	6
Reporting Spring and Summer Meetings				90	0	0
Advertising Spring and Summer Meetings				40	6	3
Printing Vol. XXVI. ... / Engraving Vol. XXVI... / Binding Vol. XXVI. ...	409	14	3			
Miscellaneous Printing ...	23	3	4			
Lithographing for Vol. XXVII.	3	5	0			
Lithographing for Vol. XXVIII.	4	17	6			
Printing Vol. XXVII. on account	200	0	0			
Despatch of Volumes	51	5	6			
				692	5	7
Expenses at Liverpool Meeting				19	13	11
Translating Papers for Meetings				15	18	9
Stationery				13	13	3
Insurance				2	10	0
Bankers' Charges				1	2	1
Petty Disbursements				55	1	5½
Gas at Meetings				3	3	0
Secretary's Salary	425	0	0			
Clerks and Messengers ...	88	5	0			
Extra Attendance	11	8	6			
				524	13	6
Balance :—						
In Treasurer's hands	970	1	10			
In Secretary's hands		—				
Annual Subscriptions ...	8	4	3			
Sales of Volumes	5	8	1			
Current Expenses ...	24	16	1½			
				1,008	10	3½
				£2,721	4	7

LIBRARY FUND.

1885.	£	s.	d.	£	s.	d.
Dec. 30. To Balance :—						
In Treasurer's hands (cash) ...	64	1	8			
„ (3 per cent. Consols)	402	0	2			
				466	1	10
1886.						
Dec. 31. Entrance Fees				289	16	0
Interest on £402 0s. 2d. Consols at 3 per cent.				11	13	2
				£767	11	0

1886.	£	s.	d.	£	s.	d.
Dec. 31. By Library Expenses				31	4	3
Balance :—						
In Treasurer's hands (cash) ...	334	6	7			
„ (3 per cent. Consols)	402	0	2			
				736	6	9
				£767	11	0

HENRY GREEN, *Treasurer.*
GEORGE HOLMES, *Secretary.*

have examined the above written entries with the books and vouchers, and find them correct,

E. A. COWPER, *Auditor.*

The following is a List of Donations to the Library :—

"Transactions of the Liverpool Engineering Society," for 1886. *Presented by the Institution.*

"Proceedings of the Royal Society," for 1886. *Presented by the Royal Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. LXXXIII., LXXXIV., LXXXV., LXXXVI., LXXXVII., and LXXXVIII. *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1886. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1886. *Presented by the Iron and Steel Institute.*

"Journal of the Society of Arts," for 1886. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vol. XXIX. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the North-East Coast Institution of Engineers and Shipbuilders," Vol. II. *Presented by the North-East Coast Institution.*

"Transactions of the North of England Institute of Mining and Mechanical Engineers," for 1886. *Presented by the North of England Institute.*

"Transactions of the Society of Engineers," for 1886. *Presented by the Society of Engineers.*

"Annual Report of the Board of Regents of the Smithsonian Institution," for 1883. *Presented by the Board of Regents.*

"Lloyd's Register of British and Foreign Shipping," for 1886-87. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Universal Register," for 1886. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1886. *Presented by the Committee of Lloyd's Register.*

"Annual Reports of the Royal National Lifeboat Institution," 1886. *Presented by the Royal Lifeboat Institution.*

"The Scientific Proceedings of the Royal Society of Dublin," for 1886. *Presented by the Royal Society of Dublin.*

"Engineer," for 1886. *Presented by the Proprietors.*

"Engineering," for 1886. *Presented by the Proprietors.*

"Iron," for 1886. *Presented by the Proprietors.*

"Iron and Coal Trades Review," for 1886. *Presented by the Proprietors.*

"Field," for 1886. *Presented by the Proprietors.*

"Army and Navy Gazette," for 1886. *Presented by the Proprietors.*

"Shipping World,' for 1886. *Presented by the Proprietors.*

"Saturday Review," for 1886. *Presented by the Proprietors.*

"Marine Engineer," for 1886. *Presented by the Proprietors.*

"English Mechanic," for 1886. *Presented by the Proprietors.*

"Revue Maritime," for 1886. *Presented by the French Ministry of Marine.*

"Rivista Maritima," for 1886. *Presented by* H. Clauson, Esq.

"Proceedings of the Royal Society of Victoria," Vol. XXI. *Presented by the Royal Society of Victoria.*

"Germanischer Lloyd," for 1886. *Presented by* Alfred A. Dietrich, Esq.

"Annalen Fur Gewerbe und Bauwesen." *Presented by the Proprietor.*

"Wochenschrift des Osterreichischen Ingenieur und Architekten-Vereines." *Presented by the Society.*

"The American Engineer," for 1886. *Presented by the Proprietors.*

"The Journal of the Franklin Institute," for 1886. *Presented by the Institute.*

"Proceedings of the United States Naval Institute," for 1886. *Presented by the Institute.*

"Ordnance Notes," for 1886. *Presented from the Ordnance Office, War Department, Washington, D.C., United States.*

"Proceedings of the Royal Society of New South Wales." *Presented by the Royal Society of New South Wales.*

"Annual Report of the Chief of Ordnance to the Secretary of War of the United States," 1886.

"Report on European Dockyards." By Naval Constructor PHILIP HICHBORN, U.S.N. *Presented by the Author.*

"The Modern Practice of Shipbuilding in Iron and Steel." By SAMUEL J. P. THEARLE, Esq., with Plates. *Presented by the Author.*

"The Naval Review of British, French, Italian, German, and Russian Large Ships of War." By Sir NATHANIEL BARNABY, K.C.B. *Presented by the Author.*

"The Steam Engine." By GEORGE C. V. HOLMES, Esq. *Presented by the Author.*

"Shipbuilding in Iron and Wood." By ANDREW MURRAY, and "Steamships," by ROBERT MURRAY. *Presented by* M. H. BRUNEL, Esq.

"Treatise on Naval Architecture." By A. F. B. CREUZE. *Presented by* M. H. BRUNEL, Esq.

"Theory and Practice of Shipbuilding." By THOMAS WHITE, jun. *Presented by* M. H. BRUNEL, Esq.

"The Art of Sailmaking." *Presented by* M. H. BRUNEL, Esq.

"Art of Rigging." By G. BIDDLECOMBE. *Presented by* M. H. BRUNEL, Esq.

"The Elements of Sailmaking." By ROBERT KIPPING. *Presented by* M. H. BRUNEL, Esq.

"A Treatise on Navigation and Nautical Astronomy." By EDWARD RIDDLE. *Presented by* M. H. BRUNEL, Esq.

"Steamers of the United States." By C. B. STUART. *Presented by* M. H. BRUNEL, Esq.

The following gentlemen (having been duly recommended by the Council) were unanimously elected Members of the Institution:—Mr. Matthew Weldon Aisbitt, Marine Surveyor and Naval Architect, Cardiff; Mr. John Denham Christie, Chief Draughtsman, Messrs. Wigham Richardson & Co., Newcastle-on-Tyne; Mr. David Evans, Professional Assistant to Inspector of Yard Accounts, Admiralty, Whitehall, London; Lieut. Goytia j Gordia, Naval Constructor Royal Spanish Corps, Spain; Mr. Frederick Bruce M. Harman, Manager, Engine Works, Messrs. R. Napier & Sons, Lancefield House, Glasgow; Mr. Henry Graham Harris, Principal Assistant to Sir Frederick Bramwell, D.C.L., F.R.S., London; Mr. Christoffer Wilhelm Hök, Scientific Superintendent, Messrs. James Laing, Deptford Yard, Sunderland; Mr. Lionel Edward Ivatts, Messrs. Claparède & Co., Société Anonyme des Anciens Etablissements, Cail, Paris; Mr. David Johnston, Superintendent Engineer, Allan Line of Steamers, Glasgow; Mr. Hans Johow, Assistant Constructor Imperial German Navy, Kiel, Germany; Mr. George Andrew Key, Engineering Manager, Australasian Steam Navigation Co., Sydney, Australia; Mr. John McIntyre, jun., Director and General Superintendent, Messrs. Robert Stephenson & Co., Newcastle-on-Tyne; Mr. Thomas Milward, Consulting Engineer and Naval Architect, Swansea; Mr. Henry M. Napier, partner in the firm of Messrs. Napier, Shanks & Bell, Shipbuilders, Glasgow; Mr. John Lewis Patterson, Manager of the Repairing and Building Works, British India Steam Navigation Company, Calcutta; Mr. Joseph Fell Redman, Marine and Engineering Superintendent, Messrs. Allan Brothers & Co., London; Mr. Andrew William Row, Chief Constructor, H.M. Dockyard, Malta; Mr. George H. F. Simey, Manager, Columbian Ironworks, Baltimore, U.S.A.; Mr. Alexander Spence, junior, partner in the firm of the Grangemouth Dockyard Company, Grangemouth; Mr. Henry Tipping, Managing Director to the Defence Vessel Construction Company, London; Mr. George Walker, Consulting Engineer and Naval Architect, London; Mr. Robert L. Weighton, Chief Draughtsman in the Marine Engine Works, Messrs. Hawthorn, Leslie & Co., Newcastle-on-Tyne; Mr. William Henry Whiting, Draughtsman and Assistant Constructor, Admiralty, Whitehall; Mons. Daniel E. Widmann, Ingenieur de la Marine Française, Paris; Mr. Arthur R. T. Woods, Assistant Superintendent Engineer to the Bahiana Steam

Navigation Company, Bahia, Brazils; Mr. Theodore Zeysing, Director of Naval Construction, Imperial German Navy, Dantzig, Prussia.

The following gentlemen were elected Associates :—Mr. Edward Burgess, Admiral P. H. Colomb, R.N., Mr. James Dixon, Mr. John Gavin, Mr. William Hayward, Mr. Arthur Holland, M.A., Mr. Henry Lamont, Mr. Vivian B. Lewes, Mr. Henry Ward Little, Mr. William Lund, Mr. Dugald MacDougall, Mr. Andrew McIlwraith, Mr. Edwin Martin, Mr. John Neilson, Mr. Charles Henry Pile, Mr. John Potter, Mr. Robert Shankland, Mr. John W. Spencer, Mr. Edmund Hannay Watts, and Captain Sydney E. Wilmot, R.N.

Since the issue of Vol. XXVII. the Institution has sustained the loss of the following Members and Associates :—William Denny, F.R.S.E., Member of Council ; T. W. Kettle, James Richards, and Robert Wyllie, Members ; Admiral Hugh Dunlop, C.B., and Ivan Mavor, Associates.

The Secretary next read the following list of names nominated by the Council to serve as Ordinary and Associate Members of Council for the ensuing year :*—Mr. Walter Brock, Mr. Richard J. Butler, Mr. William Denny, Mr. James Dunn, Mr. Francis Elgar, LL.D. ; Mr. J. MacFarlane Gray, Sir Edward J. Harland, Bart. ; Mr. Robert H. Humphrys, Mr. John Inglis, junior ; Mr. William John, Mr. Alexander C. Kirk, Mr. James Laing, Mr. Henry H. Laird, Mr. Andrew Leslie, Mr. Frank C. Marshall, Mr. Benjamin Martell, Mr. James T. Milton, Mr. Henry Morgan, Mr. William Parker, Mr. William Pearce, M.P. ; Mr. John Price, Mr. George B. Rennie, Mr. John Scott, Mr. Richard Sennett, Mr. William E. Smith, Mr. Henry F. Swan, Mr. J. Rodger Thomson, Mr. John I. Thornycroft, Mr. Philip Watts, Mr. Bernard Waymouth, Mr. Henry H. West, and A. F. Yarrow, as Members of Council ; and the Most Hon. the Marquis of Ailsa, Mr. John Corry, Professor J. H. Cotterill, F.R.S. ; Mr. E. A. Cowper, Commander R. N. Custance, R.N. ; Mr. Richard S. Donkin, M.P. ; Mr. George Duncan, Mr. R. E. Froude, Mr. Dixon Kemp, and Captain G. H. Noel, R.N. ; as Associate Members of Council.

The President (Earl of Ravensworth) next put to the Meeting the following list, containing the names of the President and Vice-Presidents and Treasurer proposed for the ensuing year, and which was unanimously adopted :—The Right Hon. the Earl of Ravensworth, President ; H.R.H. Vice-Admiral the Duke of Edinburgh, K.G. ; the Right Hon. the Earl of Northbrook, G.C.S.I. ; the Right Hon. Lord Brassey, K.C.B. ; Admiral the Right Hon. Lord John Hay, G.C.B. ; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S. ; Admiral the Right Hon. Sir Cooper Key, G.C.B., F.R.S. ; the Right Hon. W. H. Smith, M.P. ; Admiral the Hon. Arthur Duncombe, Sir W. G. Armstrong, C.B., D.C.L., F.R.S. ; Sir Nathaniel Barnaby, K.C.B. ; Sir Frederick J. Bramwell, F.R.S. ; Admiral Sir Alexander Milne, Bart., G.C.B. ; Admiral Sir Frederick W. E. Nicolson, Bart., C.B. ; Sir James Ramsden, Kt. ; Sir Edward J. Reed, K.C.B., F.R.S., M.P. ; Admiral Sir Robert Spencer Robinson, K.C.B., F.R.S. ; Vice-Admiral Thomas Brandreth, Mr. F. K. Barnes, Mr. Peter Denny, F.R.S.E. ; Mr. Henry Green, Mr. Benjamin Martell, Mr. George W. Rendel, Mr. W. H. Tindall, Mr. Bernard Waymouth, Mr. William H. White, Mr. James Wright, C.B. ; and Mr. Joseph Woolley, M.A., LL.D., as Vice-Presidents. Mr. Henry Green, Treasurer.

The President then nominated Mr. J. MacFarlane Gray and Mr. F. P. Purvis as Scrutineers to examine the voting papers.

* For List of Members of Council actually elected, *see* p. 196.

The PRESIDENT then proceeded to deliver the following Opening Address :—

Gentlemen, I rise to move the adoption of the Report which you have had read to you; but the first duty which devolves upon me is a very sad one. It has reference to the last and only recently introduced paragraph in the Report, which announces to us all the loss quite lately of a valued and highly esteemed colleague. It is my duty—a very painful duty—but nevertheless one which I shall not shrink from performing, because it is a real duty, to tell you that the Council of this Institution desires to place on record its sense of the great loss that the Institution and the country have sustained in the early death of their esteemed and honoured colleague, Mr. William Denny. Those are expressive words, Gentlemen, and I thoroughly believe that they express the feelings of everyone of us in the loss that we have sustained. We all remember the energy, the ability, and the zeal with which our late friend took his part, his valuable part, in all our discussions; we know how successful he had been in the conduct of a great business, we valued his opinions whenever they were expressed, and we all feel that his loss goes far beyond the limits of this Institution, that it will be deeply felt in his own country, and that it will be felt by all those students of naval science to whom he was a brilliant example. I am quite sure, Gentlemen, that you will approve of the proposal of the Council that our expression of sympathy and condolence be conveyed to his venerable father, who is a very great personal friend of my own, and his family, upon their great loss.

Now, Gentlemen, I must pass from that sad subject, and ask your permission to make some observations to you in the shape of introductory remarks. In looking back upon the year which has passed, I think I may describe it as a bad and uneventful year. It is chiefly remarkable, in a commercial sense, as having been perhaps the worst on record, and therefore I think you will very likely agree with me, that the less I say about it the better. We will hope for better times, and, in fact, I trust that those better times are beginning to dawn upon us; and although I think it is quite a correct expression to use in regard to the past year that it was an uneventful year, that expression cannot by possibility apply to the present year, the Jubilee of our gracious Queen; and when every loyal subject of Her Majesty throughout the length and breadth of her vast dominions is striving his utmost to do honour to that Jubilee, each in his own way, you will not, I hope, consider it altogether inappropriate to the year and to the occasion on which we are met, if I ask you to look back to the commencement of Her Majesty's reign, and if I attempt to mark in a few observations some of the steps of progress that Her Majesty herself has witnessed, during the course of her reign, in steam navigation and the progress of the Mercantile Marine of this country. Gentlemen, fifty years ago steam navigation was pronounced to be a hopeless enterprise, and that observation was made, not by unlearned persons, or ignorant persons, but by highly scientific authorities. In 1835, Dr. Lardner, who, as you all know—and I remember him perfectly—was a highly scientific authority, pronounced that any attempt to send a steamboat across the Atlantic would prove a commercial chimera; but he does not appear to have been very strongly impressed with the soundness of his own views, because he fixed, in that same year, I think, or very shortly afterwards, the ultimate size of Atlantic steamers at 800 tons and 200-horse power. Now, it is rather a singular coincidence, but if we multiply the first of those figures by ten, and multiply the second figure by sixty—a very simple sum, because I have done it—we shall arrive almost precisely at the tonnage and at the power of the *Umbria*. She is 8,000 tons, and she has an I.H.P. of 12,000, and I am informed this morning that the *Umbria* crossed the Atlantic in six days and nine hours, arriving a couple of days ago. That is a considerable stride, I think you will allow. But the learned Dr. Lardner's prognostication was very soon falsified; in fact, in 1838, only three years afterwards. But,

by the bye, Gentlemen, before I come to that, I should like to remind you of a very interesting matter in connection with a very eminent man of those days, a brother of a great friend of my own, and the uncle of our kind and generous hosts last year, the Messrs. Laird, of Birkenhead ; and we all have the most delightful recollections of our visit to Liverpool, I am quite sure. Mr. Macgregor Laird—and I want you to kindly pay attention to these words, because they are most pregnant words, and the truth of them has been fulfilled and demonstrated every year since they were uttered—Mr. Macgregor Laird, in 1835, took up the cudgels in favour of steam navigation, and particularly Atlantic navigation, and wrote a very remarkable and able letter in answer to Dr. Lardner's sinister prognostications, and used these words : "All my experience has proved that we have never yet had to complain of the size of a vessel, if the power has been proportionately increased."

There is a great maxim, I think, contained in that statement, and it only shows the value of the experience of a far-seeing, sagacious man, compared with the theoretical knowledge even of a very highly scientific man. There is one other passage in that letter of Mr. Laird's which is worthy of remark as being written fifty years ago. "Double power," he says, "propels more than double bulk," and I think that the record of steamship building will bear out the truth of both those maxims. I was going to remind you that in 1838, and curiously enough within two or three days of the time at which we are now assembled here, the *Sirius* and the *Great Western* started for New York—the *Sirius* was a little boat of 700 tons and 320-horse power, she was built at Leith—the *Great Western*, built at Bristol, started only three days after her, the *Sirius* starting on, I think, the 2nd or 3rd of April, I believe the 3rd of April. The *Great Western* was a much bigger boat, 1,340 tons old measurement, and the engines were 440-horse power. They started within three days of each other, but the more powerful boat gained two days on the passage, and they both arrived at New York within a very few hours of each other, and caused immense excitement on the other side of the Atlantic. The average speed of the *Great Western* was 208 miles, not knots, a day, which comes to eight and a small fraction miles an hour, and is by no means a bad performance, I think you will say, as an early start of steam navigation across the Atlantic. But, Gentlemen, the *Etruria* came across the other day, and, to use a sporting phrase, beat the record of the famous greyhound, the *Alaska*, because she came over in six days, nine hours, and eighteen minutes, and probably would have done it in less time, only she met with a fog on the Irish coast. There is a considerable stride, I think, in steam navigation across the Atlantic in those fifty years. In July, 1840, the great Cunard Line of Atlantic steamers was started with a small fleet of four wooden, paddle steamers *Britannia*, *Acadia*, *Caledonia*, *Columbia*, of from 1,138 to 1,156 tons, and of about 425 H.P. ; speed, 8½ knots average. In 1843 the *Great Britain* was built at Bristol for the Atlantic service—a much larger and more powerful vessel, of 3,000 tons and 1,000 H.P., and remarkable as the first iron and screw ocean steamer.

Now, Gentlemen, I should like to go on, if you will allow me, and mention a circumstance or two connected with steam navigation only thirty years ago, because we heard that very able man, the chairman of the Peninsular and Oriental Company, telling his shareholders in December last, at their annual meeting, that thirty years ago that Company built the *Himalaya*, and she was the largest merchant ship then in the world. She was so large that Mr. Sutherland found that the Company were obliged to sell her to the Admiralty, and I am bound to say I do not think the Admiralty ever made a better purchase. She has done true and loyal service to the Queen ever since. I believe she is a good ship now, and I hope the Peninsular and Oriental Company will be fortunate enough to have a great many more *Himalayas*. And further what did he tell the world?—that the Company were now building four vessels nearly twice her size. That is truly a considerable advance in steam-

ship construction in thirty years. Mr. Sutherland is too able a man to have forgotten it, but I should like to fill up the blank—the *Himalaya* could not have possessed the title he gave her for more than a few months, because it so happened that the *Great Eastern* was launched, or at least begun to be launched, in 1857. She started her launch in the early days of November, and she floated of her own accord on the last day of January following, so that she was three months on that passage; however, it was attained at last. I should like to dwell a little on this, because certainly the launch of that ship is a great event in Her Majesty's reign; because, notwithstanding all that has occurred, and all that has been said, and all the abuse heaped upon her, I believe the *Great Eastern* to be certainly the biggest, and I believe the strongest ship that ever was built. I have always taken a great interest in this ship, because of our late lamented friend Mr. Scott Russell, and the great engineer also who designed her; but it is a very satisfactory thing to my mind, and I think to everybody who considers it, that there is a prospect of that great ship rising from her ashes like a phœnix, and that too, shortly, because it really is not a figure of speech to say that the last time I saw her, and many others saw her, she was in dust and ashes lying in the Mersey, degraded to the position of a dancing saloon, her magnificent sides covered with every sort of parti-coloured advertisements, and a parcel of acrobats crawling about in her maintop instead of sailors. It is satisfactory to hear that she has been purchased, and that new engines are to be put into her. I presume also she will have twin screws, because surely they will not trust such a ship as that on a distant ocean voyage with a single screw, and she is to be the pioneer of a new line of fast steamers to Australia. Now there is a very remarkable circumstance which I should like to point out to you in the history of this ship. She has been several times across the Atlantic, she has conveyed troops to Canada, she has laid Atlantic cables, and she has been more useful I believe in that capacity than in any other, but she has never been to Australia, and she was designed for the Australian trade purposely, and built for that trade—she has never been there; but we all hope, as I said before, that this new adventure of hers will prove a successful one. I believe that she was really too big for the trade, but I think that remark can hardly apply now, and we hope that it will not; but I think the secret may be told in very few words, that she consumed 210 tons of coal per day, and she was designed to go to Melbourne in forty-five to fifty days, that was the estimate formed of her performances, and she was to run at a rate of speed of 15 knots. But she never attained that speed on any of her voyages, and I do not believe that, except once or twice, under the most favourable circumstances, wind favourable and aided by her sails, she ever did more than 14½ knots; but it so happens in regard to the consumption of coal that the *Etruria* beats her even in that, for the *Etruria* consumes 300 tons of coal per day, that is 12 tons an hour; but mark the difference. Her average in nine consecutive voyages has been 18 knots an hour, and, as I told you, she came over here the other day making the fastest passage which was ever made by a steamship across the Atlantic.

Well, now, Gentlemen, going on to point out the great improvements that have been effected during the fifty years of Her Majesty's reign, I should like, with your kind permission, to allude to two vessels only, which I think fairly describe the latest and most improved types of ocean steamships. One is a Weir-built ship and the other is a Clyde-built ship, and in mentioning them I shall not be accused of any particular favour or partiality to my own river, because neither of them belongs to the Tyne, but they are remarkable types of ships, and they have characteristics which I think will interest those who hear me when I very shortly describe them. The one is the *Trans-Pacific*. She was originally named *Nulli Secunda*, and many of you who were at Liverpool will remember how much interest was taken in her model. It was a very beautiful model. This vessel is a cargo boat, and she is a remarkable and good illustration of the immense progress that has been made in steamship building up to the present

time. She is 440 ft. long, 48 ft. in breadth, and her hold is 32½ ft. She is entirely composed of Siemens steel, with the exception of her deck-houses, which are of iron. She has two steel decks, fore and aft, and a third deck of pine. The upper steel deck is sheathed. She has a fourth deck in her fore-hold, and she is further subdivided by seven water-tight bulkheads. Each of the compartments—this is a remarkable characteristic of the ship—is about of equal capacity, and each hold is fitted with a large hatchway and two patent swinging hydraulic cranes. The midship hold is further subdivided by bulkheads, and is also fitted with a third crane. All these holds can be emptied at one and the same time. She is very high between her decks, and consequently would be an extremely valuable vessel for the conveyance of troops or cattle, or any live cargo. Her gross register is 5,600 tons, and her speed, loaded, is 12 knots, or 14 knots with passengers, on a consumption of about 50 tons of coal per day. Her engines are triple expansion, of 4,000 I.H.P. I think you will say from that short description that she is a very fine specimen of a modern cargo boat. Now, the next vessel I want to allude to is that magnificent vessel which left the Clyde only a short time ago, described as being the largest vessel of her class—the largest passenger steamer that ever entered the Thames. I mean the *Ormuz*. She was built by the Fairfield Company, and she has lately arrived at Adelaide within 31 days' steaming. She has remarkable characteristics. She is an Orient Liner. Her length is 481 ft., her breadth is 52 ft., her depth 37 ft., her displacement at the load line 10,500 tons, her gross registered tonnage is 6,116 tons, her I.H.P. 4,000; her speed was 18 knots on her trial trip, and she is divided into ten compartments; and this is the remarkable characteristic about the ship—that she can be made water-tight by closing her iron doors by powerful screws worked from the main-deck. There is another peculiarity about her—that the doors nearest the engine-room fall by their own weight, by means of the withdrawal of a short iron bolt, and they are sharp at the bottom. I hope they will not serve as a guillotine to anybody who unfortunately may be passing under them, but I cannot help thinking that the designer of this vessel must have had in his mind the lamentable occurrence of the *Oregon*, because the weight of these doors and their sharpness is sufficient to cut through any obstacle which there might be to prevent their passage into their case. Those are her peculiarities, and I venture to mention them because I think they are very fine specimen illustrations of the vast improvement that has taken place, one being a cargo boat, the other being a passenger steamer quite lately built.

Well, now, with all this immense progress and improvement, it is a very melancholy thing to consider, but it is, I am afraid, too true, that within the last three years steamship property has depreciated no less than 30 per cent. We have high authority for it, and I do not think, when we come to consider it, the causes of that depreciation are very far to seek. I must, by the bye, allude to this, because, before I proceed further, I wish to show you a very interesting circumstance—that is the increased tonnage, as it has to do a good deal with that depreciation—the increase of the tonnage that has taken place in steamers since 1855, only thirty years ago. These figures are taken from a very valuable work published by Lloyd's—"Lloyd's Universal Register"—the accuracy of which we cannot, of course, dispute. The figures were used by the very able President of our local institution, the North-East Coast Institution of Shipbuilders and Engineers, whom I am sorry to see is not here to-day. Those figures, which were taken as the basis for his statements, were from Lloyd's Register, and I should like just in passing to remind everybody of his lecture. It dealt with a subject which is almost entirely novel, and if anybody wishes to pursue it, I cannot do better than to recommend him to turn to that lecture and study the figures, because the subjects he dealt with were not only the size of our merchant fleets, the numbers of them, but also their condition. It is a very interesting subject, and I allude to it in passing. Having

disburdened my breast of the plagiarism, I will now use two or three figures to show you what the increase of tonnage in our steamers has been during the last thirty years. You will find it very interesting. From 200 to 500 tons, the increase has been four-fold; from 500 to 1,000, seven-fold; from 1,000 to 1,500, twenty-five-fold; from 1,500 to 2,000, forty-three-fold; from 2,000 to 2,500, thirty-seven-fold; 2,500 to 3,000, twenty-eight-fold; and 3,000 to 4,000 tons, thirty-seven-fold. I think, Gentlemen, that you will admit that that is a marvellous advance in the size of steamers, bearing in mind Mr. Macgregor Laird's prognostication that size eventually would mean power, and I take it that you would all agree to that maxim nowadays, that size really does mean power. The figures that I have just quoted refer to no less a number of steamers than 7,889, of 9,855,560 gross tons, and no less than 44 per cent. of that vast aggregate tonnage has been built since the year 1880, or very nearly half. Now, Gentlemen, I began by talking of the depreciation in the value of steamers in the last two or three years. I think that that goes a long way to explain the depreciation, because, no doubt, an immense amount of that building, or at least a very large amount, was of a highly speculative character. We also know that ship-owning has fallen of late years into a totally new set of hands, and a vast number of persons, I am afraid, have invested their savings in shipping who know absolutely nothing about the business; in fact, know so little that they have hardly, many of them, been able to select managers who did know much more. That, I think, in itself has led to a great amount of this speculative building, which undoubtedly accounts for a good deal of the depreciation, but not entirely. The establishment of shipping companies on the limited liability principle, of course, increased that speculation. But that is not all. Formerly England used to build ships for all the world, and now all the world is building ships for itself. There is another reason, I think—and in the face of declining trade it is easy to conceive that such a depreciation as I have mentioned should have taken place—the foreign competition, which used to be laughed at, but which has become a very stern reality, is largely assisted by foreign States by an artificial system of bounties, and, although it suits some authorities to laugh at bounties, it is a fact that they are a very serious handicap, and so long as those nations are found to pay those bounties that handicap will remain, and that is a very serious consideration to those who are competing in the great ocean lines of steam navigation. I think that that is pretty nearly enough to account for this depression. In the five years from 1881 to 1886 there were no less than four millions of tons of steamers built, as against two millions of tons in either of the preceding five years, namely from 1876 to 1880, and from 1871 to 1875. I will not trouble you with statistics upon that point, but I may broadly say that speculative building appears last year to have ceased, I hope, for some time, because the aggregate amount of tonnage built, in round numbers, is 460,000 tons in our various shipbuilding establishments, and the amount removed from the Register by sales, losses, and so on, was about 400,000, and the declension is still going on. It is largely in sailing ships, but still that is a very small increase over the actual amount of removals from the Register in one year, so that that evil is probably correcting itself.

Well, now, Gentlemen, there are two matters which I think account largely for, and are rather chief features in, the vast and latest improvement that has taken place in shipbuilding in the time over which these remarks extend; one is the introduction of the triple-expansion engine, and the other is the employment of steel in the building of ships. I believe that a great proportion of ocean-going steamers are now fitted with the triple-expansion engine. I observe that high authorities do not think it safe to calculate upon any much larger saving of fuel by the use of the triple-expansion engine than 25 per cent., but they all agree upon this point, that it is an indispensable condition of giving the full advantage to that principle of triple expansion that each cylinder should be provided

with its own crank. I believe that to be a maxim which has received general acceptance. The 25 per cent. saving of fuel must be taken at a pressure of 150, which we all know is a very usual pressure. Well, now, there is another point upon which there does not seem to be the same concurrence of opinion, and it is an interesting point. I will just allude to it in passing. I think there is a good deal of difference of opinion as to whether, in order to obtain the full amount of work out of a given body of steam, it is or is not necessary to jacket the high-pressure cylinder. There seems to be a good deal of discussion going on upon that point, which is a very interesting one. I heard a very high authority say the other day that he had doubts whether the jacketing was worth the trouble and bother which it took. That is a matter, of course, for engineers to settle, but there seems to be a great deal of discussion going on about it at the present time. I have alluded to the second great improvement, the introduction of steel as a material for shipbuilding. I do not believe that these pressures could have been reached had it not been for the introduction of steel for boilers, which enabled these great pressures to be used with safety. Not only that, but we find these high pressures do not cause detriment to the boilers. It is not only in the hulls of ships that steel is now so largely used, but its use is increasing in the working parts of the machinery; and that is a very important improvement, because the use of steel in the working parts of the machinery and the engines admits of a higher piston speed, with no more wear and tear, and that higher piston speed again admits of smaller engines, with equal power, or of much greater power with equal sized engines. Six years ago steel only represented 10 per cent. of our steam tonnage, and it is now considerably more than 50 per cent., and upon the Clyde I believe no less than 66 per cent. of the vessels built are of steel.

I have tried to mark some of the chief strides that have been made in the construction of ships and in steam navigation during Her Majesty's reign. I think if ever the phrase progress by leaps and bounds could be used with propriety, that phrase may be claimed for the progress of steam navigation and steam shipbuilding during the past fifty years; but, although steam has arrived at this pitch of perfection which we observe, and although there is extensive use made of steel, I do not think that anybody would contend that we have even yet reached perfection in either the manufacture or the manipulation of that metal, or that there may not be yet a good deal to be learned in both those respects with regard to its use. But hardly has it arrived at this high standard when we find another rival in the field; and if even a considerable portion of what is claimed for this new material be true, it is likely to prove a very formidable rival indeed in the future. I was going to say I wonder whether Her Gracious Majesty, whose life we all hope will be long prolonged, will witness during the remainder of her reign as great progress and discoveries as she has seen in the past. Perhaps I shall be laughed at when I say I think it is quite within the bounds of possibility that she may, and from the few observations which I am going to make on this point, I think you will see I am justified in making such a prophecy. There is a new rival in the field, and that is aluminium—aluminium manufactured by the electric process and the intense heat which is generated by that process. Now it is claimed for aluminium that it is only one-third the weight of iron; it is as tenacious as iron—as fibrous as iron; that it is malleable as gold, and that it resists all corrosion. But it is as an alloy that its great value seems to consist; as an alloy with copper—that is, as a bronze—its tensile strength amounts to no less than 100,000 lb. per square inch. It casts well and it works well, and its tensile strength in casting has been tested up to 128,000 pounds. Now, of course, I do not expect any gentleman to believe me upon such a point as this, but I have had an opportunity of talking lately with certainly two very eminent metallurgists, and they both agree in thinking and believing that there is a very great future indeed in store for this new metal; but I should like to quote to you, in support of

my own belief, opinions that are worth hearing. *Engineering*, writing on this subject so lately as last July, says this :—

"An ample supply of this material would utterly transform all engineering. What a revolution it would effect in naval architecture."

Those opinions must be interesting both to the naval architect and to the marine engineer. Another scientific journal, writing some years ago—in 1883, said this : "Wherever there is necessity for metal work which shall combine flexibility with strength, and which shall be free from corrosion" —that seems to be one of its most remarkable qualities—"there aluminium will reign supreme." Now aluminium at this moment stands on very much the same footing as the mineral oils of which I have taken occasion to speak before, of which we have heard so much, and for which trade so many magnificent tank steamers are being built by our shipbuilders at this moment in different parts of the country. The conditions, I say, are similar, because it is a commercial question, the question of the price; but if the price is brought down to the point which is claimed for it by this extraordinary electrical process of manufacture, it seems to me that it possesses qualities far above those even which are possessed by our best mild steel, and the eyes of the scientific world will, inevitably, be fixed firmly on aluminium as a material for shipbuilding, and upon mineral oil as fuel for the next few years.

Now, Gentlemen, I have detained you long enough, and there is only one other observation which I will ask your permission to make. I should hardly feel that I was justified in sitting down without alluding to it. The longer I have been connected with this Institution, the more I have been struck with its value as an educational feature in this country, and it is only fair, I think, to those eminent men who have taken part in the lectures organised under the auspices of the Worshipful Company of Shipwrights, and which have been read this winter, to recognise the valuable public services that those men have performed, for the country at large, in reading those papers. I think it would be impossible to over-estimate their value, whether you regard them as historical or as illustrative of the gigantic progress which has been made in steam navigation, both for the purposes of the Royal Navy and for the mercantile service of this country. Not the least valuable of those papers was read by the able President ; I am not sure whether he is called the President or the Master of the Shipwrights' Company, but I do say that the country is indebted to those gentlemen, and I am delighted to see that the chief papers have been provided and read by the most eminent members of this Institution. I say that they will be of immense value to students, and I hope, now that they have once begun, that that course of lectures may continue.

Gentlemen, I am extremely obliged to you for allowing me to make these few observations. I thought it was not altogether inappropriate to this year that I should note some of those landmarks which I have only very, very faintly traced, because it is a subject that would take volumes to do justice to, but they are connected with the year which is in all our minds, the Jubilee of Her Majesty, and, therefore, I have ventured to make these observations with reference to that progress, and I thank you very much for your kindness in listening to me. (Cheers.)

I now call on Sir Nathaniel Barnaby to read his paper.

Before the reading of Mr. Dixon Kemp's Paper on Thursday, March 31st, the Scrutineers appointed to examine the Ballot Papers for the Election of the New Council presented the following Report:—

Society of Arts, John Street, Adelphi, London, W.C.,
Wednesday, March 30, 1887.

The Right Hon. the Earl of Ravensworth, *President:*

My Lord,—We have examined the Voting Papers for the Council for the ensuing year, and having taken account of the death of Mr. W. Denny, and the Election of Messrs. Martell and Waymouth as Vice-Presidents, we find that the following have been duly elected Members of Council and Associate Members of Council respectively:—

Members of Council:—

Brock, W.
Dunn, J.
Elgar, F.
Gray, J. MacF.
Harland, Sir E. J.
Humphrys, R. H.
Inglis, J.
John, W.
Kirk, A. C.
Laing, J.
Laird, H. H.
Marshall, F. C.
Milton, J. T.
Morgan, H.
Parker, W.
Price, J.
Rennie, G. B.
Scott, John.
Sennett, R.
Smith, W. E.
Thomson, J. R.
Thornycroft, J. I.
Watts, P.
West, H. H.
Yarrow, A. F.

Associate Members of Council:—

Ailsa, Marquis of.
Corry, J.
Cotterill, J. H.
Custance, Captain, R.N.
Duncan, George.
Froude, R. E.
Kemp, Dixon.
Noel, Captain, R.N.

We have the honour to be,

Your Lordship's obedient Servants,

J. M. GRAY.
F. P. PURVIS.

THE "MERCHANT SERVICE" AND THE "ROYAL NAVY."

By Sir Nathaniel Barnaby, K.C.B., Vice-President.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 30th, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The Shipwrights' Company did me the honour to ask me to give a lecture as one of the recent Mansion House series, and I had proposed to take this subject. I was prevented from making a final arrangement in the matter, and the lecture was never given.

Within the last few days the Council of this Institution has asked me to read a paper here on the subject I had chosen for that lecture.

I do so with the advantage that since I prepared the paper the First Lord of the Admiralty has laid before Parliament proposals which are a distinct advance in the course I had desired to advocate. I had wished to support Lord George Hamilton and Lord Charles Beresford in the policy they had indicated in recent public statements—a policy which sought for some organisation in the Mercantile Marine in order to increase the power of national defence.

The necessity for organisation arises from the following facts:—

(1) A fast mail or passenger steamer may be as efficient a factor in a naval war as an ordinary war cruiser which has cost a quarter of a million sterling, and has a crew of five or six hundred men.

There are certain services which she may perform much better than the regular war-ship, by reason of her greater size and superior travelling power.

For engaging with a regular ship of war the inferiority of existing merchant ships of the best and most powerful type is obvious; but on the other hand, their superiority when properly armed to other merchant ships unarmed, or, say, of less size or speed, must be admitted.

(2) Excepting these few fast mail and passenger steamers, merchant shipping is incapable of offering any resistance whatever to an enemy possessing speed and a small armament.

High steam speeds at sea have wrought this great change in the military character

of trading ships, viz., that all sailing ships—and we have eight thousand of them of 100 tons net and upwards—have become absolutely helpless; and of the nearly six thousand steamships of 100 tons gross and upwards, more than nine-tenths would be incapable of offering any resistance against a single ship of the superior class included within the remaining tenth.

This superior class has, by comparison, acquired a value far higher than was ever possessed by a trading ship in the days of sail power.

In those days the fighting value of the armed Indiaman was fully recognised. There is no reason why, in a naval war, many a brilliant passage of history may not be associated with ships which are not reckoned as part of the "Navy." These ships will certainly force themselves into prominence, either in our hands or in those of our enemies.

(3) Provision is made by the State for a reserve of seamen who are drilled periodically, and paid by it, and are liable to be called upon to serve in a war. But there is no link of any kind to connect the useful ships with the trained men.

By organisation, these superior ships under our own flag may be made a real State possession, and they may be manned mainly by men trained in the Royal Navy, seamen and marines. They may be made available for immediate service on the outbreak of war at any part of the world where they may happen to be, by the action of the Commander-in-Chief on the station.

Without organisation, the ships may be found to be seriously defective in some points of detail in construction, which owners would have gladly corrected had they been advised and encouraged to do so.

Without organisation, ships from which such defects have been removed may find themselves put on one side in State employment in favour of others in which they flagrantly exist, and even in favour of ships belonging to a foreign State.

Without organisation, ships of the highest speed, and carefully built, may be found at time of need, when the Commander-in-Chief on a foreign station imperatively needs their services, to have not a single trained officer or seaman on board. Thousands of Royal Reserve men may be found in ships having no defensive power whatever, and none in the few ships which have so high a value.

These are, unfortunately, the actual facts.

Not only the Post Office, but the Admiralty itself, employs ships which the Admiralty officers have declared to be seriously defective in structural security. And as to the men, it will be found that the most splendid ships now under the English flag have not a single Royal Naval Reserve man in their crews.

How does this come about? By the following arrangement:—

There are some 250 ships designed and built for fighting.

Including the Royal Naval Reserve there are some 80,000 officers and men for service afloat in these ships.

This *personnel* and *materiel*, known as the British "Navy," is placed under the control of a Cabinet Minister and a powerful Naval Board, to whom the defence of our maritime possessions is entrusted.

There are under the same flag, but built for commerce, near 14,000 ships of 100 tons and upwards, with crews of some 300,000 men.

This is known as the Merchant Service. It is under the control of "The Lords of the Committee of Privy Council appointed for the consideration of matters relating to trade and foreign plantations." They are described in all Acts of Parliament, deeds, contracts, and other instruments by the official title of "The Board of Trade," without expressing their names.

The Lord Chancellor and the Speaker of the House of Commons are both members of this Board, so also are the Principal Secretaries of State, but no one connected with the Royal Navy is included. Even the First Lord of the Admiralty is shut out from the long list of members.

Of the thirteen millions of money taken for the Navy, the only appropriation touching the efficiency of the Mercantile Marine in its military aspect is the retaining fee, and the expense of periodical drill for 18,000 men.

The high State officers named above as constituting the Board of Trade, inspect all passenger ships and give certificates that the hull of the ship is sufficient for the service intended; is in good condition; and that the partitions, &c., are in the condition required by Act of Parliament. Acting on this certificate, passages are made, and the Admiralty itself employs for the transport of troops ships having this security and no other.

But what is the real worth of the certificate? It is in evidence that since 1862 the Board of Trade surveyors have had no power to require given water-tight partitions to be fitted in the holds of passenger steamships, although the Board has had no doubt as to the necessity for proper and sufficient water-tight partitions, and has had no doubt that the proper authorities would insist on their being fitted in all steamships employed in the conveyance of mails.

Whatever may have been the expectation of the Board of Trade in leaving builders and designers unfettered in this respect, it is quite certain that Her Majesty's mails are now carried in ships having no such sufficient bulkhead division; and that the Post-master-General does not trouble himself to ask whether they have or not.

The ship that has such division has no advantage whatever, in the Postal service, over one that has not.

We are, then, in this position :—The Admiralty and the Board of Trade are agreed that certain structural provisions should be insisted on in mail and passenger ships, and yet the latter issue certificates of fitness to ships having no such provision, and the Post Office and the Admiralty employ the ships.

Sir Thomas Farrer may be quite right in contending that the Board of Trade should not tie down builders and designers by general statutory regulations, but should leave them free to provide the necessary strength and security in their ships.

But this license is inconsistent with the practice of giving certificates of fitness without proper general examination, and notwithstanding that the builders have violated the special condition which is agreed on all hands to be essential to reasonable security.

There are hundreds of British steam passenger ships, of large size, classed at Lloyd's, and running with Board of Trade certificates, of which it may be confidently said that they would inevitably sink if a hole a square foot in area were made in the bottom plating only a few feet below water. How easily such a hole may be made in an iron or steel plate of bottom we all know.

If the Board of Trade gave no such certificates the evil might be expected to right itself.

The Government might then inquire into causes of loss without being hampered by the certificates of their own officers.

I feel confident that wreck inquiries would then throw light on causes of loss which are now accepted as inevitable, but would soon be seen to be capable of remedy. The voluntary associations for classifying ships would thus have their hands strengthened, and would be able to insist on proper subdivision as a condition of register on their books.

Surveys, assignment of load-line and freeboard, certificates, and classification for the guidance of merchants, underwriters, and passengers should be left to the admirable voluntary associations formed by joint committees of underwriters, shipowners, and merchants.

The rules of Lloyd's Register for freeboard have been virtually adopted by the recent excellent Load Line Committee, and the Committee of Lloyd's Register might well be entrusted with the assignment of a load-line, just as they now assign the spacing of the frames, and thickness of the plating in the hull. Ships not classed as to load-line would be in the same position as those not classed for structure.

The Committee of Lloyd's Register now class one-third of all the classed shipping in the world. To it and to similar institutions the Government might well entrust the care of shipbuilding, keeping its own hands free while watching the course taken by them, and instituting searching inquiries into the causes of losses which might appear to have been avoidable.

But while the system of survey and certificate by a Government department may thus be seen to be inconsistent with proper inquiry into the causes of loss, the advantage of modern legislation in improving the efficiency and comfort of officers and crews cannot be questioned. The efficiency and well-being of a body of men six or seven times as numerous as the seamen and marines in the Royal Navy is a very serious matter.

Experience has shown that commercial interests cannot be made to cover this ground satisfactorily.

Notwithstanding the benefit conferred by the Mercantile Marine Act of 1850, the Merchant Shipping Act of 1854, and subsequent Acts, very much remains to be done before the lot of the sailor in his housings and surroundings on shipboard can be made to compare at all favourably with life on shore.

Those who have acquainted themselves with forecastle life, know how seriously the health of the men suffers from leaks in decks overhead, and condensation upon the bare iron plating, left bare to avoid the worse plague of vermin which soft wood lining fosters.

Our maritime interests are much more dependent on this efficiency and well-being than on that of either our Army or our Royal Navy.

Is it well to entrust it to such control as it now has ?

Ought there not to be a Secretary of State for the Navy, having the care of this vast interest, with the assistance of competent men, such as may be found all over the Empire ?

Might not the "Royal Navy" be regarded not as *the* Navy, but as a highly specialised department of the British Navy, presided over, as at present, by a Board of Admiralty, but subject also to the Secretary of State for the Navy ?

These steamships, built by private enterprise, are an extension of the Queen's dominions. Each of them is a new British territory, often very rich and populous.

Nor does there appear to be any reason to limit their increase in size. It is conceivable that steel ships will be built richer and more populous than many a famous English town—ships not only carrying for traders, but trading on their own account; and providing for permanent residence as well as for transport. Such ships must be

armed and garrisoned, and must unite the mercantile and military elements within themselves.

We have not reached this stage yet, but we have reached the position that certain ships built by private enterprise have great national value. Their transfer to a hostile flag would be a grave national misfortune. It is unendurable that this value should not be recognised by the State authorities.

No care is taken to foster its valuable national features, or to preserve its national character. War-ships are built and maintained at the expense of the State which would be of less value in a war, but nothing is done to economise the national resources which are in private hands by maritime organisation.

The steps that have already been taken by the Admiralty are said to have had excellent results in improving the character of the passenger ships built within the last ten years. The time has now arrived, it is to be hoped, for organisation.

To Mr. Ward Hunt, Mr. W. H. Smith, and Lord Northbrook is due all that has been hitherto effected. Lord George Hamilton has an opportunity which he appears to be disposed to use.

He deserves the best wishes of all who know the conditions under which the next great naval war must be fought, and who realise the impossibility of protecting our slow shipping by regular ships of war.

To provide an efficient armament for the fast merchant shipping, and to organise it, is the immediate pressing need of the British Navy, and of the Empire.

The organisation must include the engagement of seamen and marines already trained in the Royal Navy; the seamen for the ship work, and the marines for the domestic work on shipboard.

The full pay and pension provision for such men as may be thus engaged might be found by the State.

By this means the number of warrant, petty, and non-commissioned officers and men might be greatly increased, without a corresponding increase in war shipping.

To effect this it is desirable that the close and vital relations between the ships and the men of the two great divisions of our floating Empire should be recognised, and that their present administrative separation should cease.

It has been admitted that the best of the merchant ships are exceedingly defective in their provision against vital injury from shot, and in collision.

The best that it has been possible to accomplish, under existing conditions, still leaves these ships with only one propeller, and with an exposed steering arrangement from rudder head to steering wheel.

Both these defects are avoidable without loss of commercial efficiency, but owners cannot be expected to run risks as to commercial efficiency, and to accept possible increase in engine-room expenditure, at their own sole expense.

So also in the matter of subdivision into compartments, the best that has been done in ships like the *Oregon* falls far short of what might be done without loss of efficiency, but with some increase in cost of building and maintenance. Owners are known to be ready to build ships with two screws, with protected steering gear, and with far better subdivision, if the Government would admit that these are matters of national interest, and would treat them and their ships in that spirit.

In a paper explanatory of Naval estimates, recently issued by the First Lord of the Admiralty, there is a section upon the utilisation of auxiliary resources. It is there stated that the White Star Company had expressed their willingness to build two vessels, to be approved by the Admiralty, of a speed and strength superior to any merchant ship afloat, with engines and boilers below water, with fittings for guns built in during construction, and, when manned, with half crews of Naval Reserve men.

By the payment of an annual subsidy the use of these ships will be obtained, under an agreement for five years, at a price fixed beforehand, both as regards hire and sale.

This arrangement with Mr. Ismay, and a similar one made with the Cunard Company for three of their ships, are the final outcome of a proposal made by Mr. Ismay in 1878.

At that date he offered the following terms:—

He was willing to make an agreement with the Admiralty for the transfer of certain ships for the purposes of the State in time of war as follows:—

1. The payment of ten shillings per ton (gross register tonnage) per annum as a retainer when not employed by the Admiralty.

2. The payment of twenty shillings per ton (gross register tonnage) per month for each particular ship when and so long as it is employed by the Government.

3. The ship to be taken at the entire risk and expense of the Government when exclusively employed by the State.

The value of the ship to be determined by the current building rate of the time she is accepted for the auxiliary fleet; and a rebate of 6 per cent. per annum to be made for depreciation of value.

4. Each ship is at first to be placed on the list for a period of three or five years, subject afterwards to twelve months' notice.

5. When a ship is taken over for employment by the Government, it shall be for a period of not less than six months.

6. An agreed number of the crew shall at all times consist of Naval Reserve men.

7. If a ship is carrying H.M. mails when it is proposed to annex her to the auxiliary fleet, the approval of the Postmaster-General is to be obtained.

This seed, for which we had to thank Mr. Ismay, was planted at the Admiralty nine years ago.

It was recommended that £50,000 should be taken in Navy estimates for securing thirty selected ships for the year.

It was pointed out that in course of time we might hope to get in such ships twin screws; a double bottom in the centre part of the ship; better subdivision into compartments; and more breadth amidships, so as to get deeper coal-bunkers abreast of the machinery for its better protection. Under the cold shade of the Admiralty the seed has taken nine years to make any appearance, although it received constant attention.

If it has taken nine years to put forth the feeble shoot over which we are rejoicing, when may we expect to see a robust and well-developed system?

It has needed the forcing provided by the events attending the anticipated war with Russia, and the recent action of the Post Office as to German ships, to get so much as Lord George Hamilton has announced, little as it is.

I am afraid that no Board of Admiralty can deal with this question fully and fairly. It is impossible that such a body can be trusted to find money out of Naval Votes for what is not regarded as the Royal Navy. What I think is wanted is a Secretary of State for the Navy, who would unite the interests of the "Merchant Shipping" and the "Royal Navy," and form a truly National Marine.

APPENDIX.

[*Extract from Statement with Navy Estimates*, 1887-88.]

Utilisation of Auxiliary Resources.

The inquiries, which an Intelligence Department must needs make, brought before the Board in forcible contrast the great disproportion between the volume of floating commerce of the Empire to be protected and the force at present available to protect it, compared with the mercantile and war marine of foreign nations. To bring the British Navy and commerce into the same relative proportion as that which exists elsewhere in Europe is neither needed nor practicable. To carry out a plan which, at the approach of war, would immediately convert our fastest and most powerful merchant-vessels into effective war-cruisers, and thus turn the assailed into assailants, seemed a natural solution of the difficulty; but there were various obstacles to its realisation. The cost of retainers, the difficulty of providing crews and stokers, the delay in the alterations necessary, the contingency that when wanted the vessel might be at the other end of the world—these difficulties in combination deterred previous Boards from making the experiment.

The enormous sums spent in taking up vessels in 1885, many of which never left the harbour, and the long delay in getting the guns and fittings into the *Oregon*, the only vessel thoroughly equipped of all those hired, impressed upon my colleagues and myself the duty of taking some action in the matter. Exceptional speed and strength are the only desiderata of a mercantile cruiser. It occurred to us that the Post Office expenditure might be utilised, and that if we worked in combination, postal contracts could be associated with conditions by which the use of the vessels carrying the mails might under certain contingencies be economically secured to the State. The revision of the North American contract was a most favourable opportunity for a trial of the idea. The White Star Company, one of the tenderers, had, in August last, expressed their willingness to build two vessels to be approved by the Admiralty, of a speed and strength superior to any merchant-ship afloat, with engines and boilers below water, with fittings for guns built in during construction, and, when manned, with half crews of Naval Reserve men.

In return for their use, the Company requested an annual subsidy which would recoup the owners a portion of the larger outlay the exceptional construction of the vessels required.

The Cunard Company, another of the tenderers, has the fastest English ships afloat. A large portion of the officers and men in the employ of the Cunard Company are Naval Reserve men. Their ships are never more than eight days' distant from Liverpool, and, therefore, always obtainable at short notice.

The Admiralty, after full consultation with the Treasury and Post Office, commenced negotiations with these two Companies.

They were influenced greatly by this consideration, that merchant-vessels, when armed, to be really serviceable, should have exceptional speed and coal capacity, enabling them to overhaul the weak and to escape from the strong.

Such exceptional speed entails a primary cost in engines and boilers, and a consumption in coal that renders the remunerative employment of the vessel very difficult. Only a few of the richest and best-conducted passenger lines can afford to build such vessels, and the profits derived from their employment in recent years have been small.

Unless some inducement is given by the English Government to continue the building of such vessels, they must diminish in number; whereas abroad, by subsidies, their construction is directly encouraged. It is neither to the credit of the country nor for the advantage of our marine that vessels of this class should mostly be under foreign flags.

The arrangement made with the two companies differs in detail, but is the same in principle.

By the payment of an annual subsidy, reduced one-fourth so long as the mail contract lasts, the Government obtain from the Cunard Company the use of the *Aurania*, *Etruria*, and *Umbria*, in time of emergency at a price fixed both as regards hire or sale. The necessary platforms and fittings for carrying guns are to be put in at once. The crews of the ships to be half Naval Reserve men; the owner to take charge of the gun mountings required. Under this arrangement, it is believed that within a week all three vessels could be fitted, armed, stored, and manned as armed cruisers. The use, at fixed prices, of the remainder of the Fleet, if required, was a secondary condition of the contract.

With the White Star the arrangement was practically the same, except that no payment was to be made till the two new ships to be built were ready for sea.

By this arrangement the Admiralty have obtained, at a moderate annual cost, the use for five years of the three fastest steamers afloat, and two even faster, when constructed.

Negotiations with the Australian Colonies have for some time past been carried on, which, though not concluded, will, we hope, result in those countries contributing towards an extension of the Imperial Navy, and maintaining, as an integral part of the Fleet, an Australian squadron, in addition to the force which has hitherto been stationed in those waters.

DISCUSSION.

Admiral Sir John Hay (Vice-President): My Lord, I am very happy to express my own thanks to Sir Nathaniel Barnaby for this interesting paper, and I think we may congratulate ourselves that the previous opportunity which was afforded to him of reading it was not availed of, but that we have had the advantage of hearing it fresh and interesting on this occasion. I, perhaps, may be allowed to say, with reference to a point in this paper, that (although I am afraid not nearly enough was done for the purpose) in the year 1868, when I had the honour of being a Lord of the Admiralty, Sir Alexander Milne, who is one of the Vice-Presidents of this Institution, being then First Sea Lord, had the credit of first making a proposal and of going into the arrangements which seemed to be necessary for obtaining the services of merchant ships to supplement the Royal Navy in time of war. I am well aware of that fact, because, happening to be a Junior Lord, and what is called Gunnery Lord, I was put into communication with the War Office to endeavour to obtain a supply of five hundred guns which were estimated for in the estimates of the years 1868 and 1869, with their fittings, for the purpose of arming certain merchant ships which were supposed to be available for the purpose. But I believe that fell into desuetude. There was a time of what was called economy, which was really extravagance, which gave us no ships and very bad cutlasses, which came off in the year 1871. When Sir Alexander Milne came again into office in 1874, with Mr. Ward Hunt, he again brought up a proposition which had been sanctioned by your predecessor as First Lord of the Admiralty, Sir John Packington, the late Lord Hampton. Mr. Ward Hunt carried it out, or, rather, began the arrangements, as Sir Nathaniel Barnaby has very properly pointed out, and it is now, after some twenty years of consideration, gradually being adopted for the advantage of the country. It is quite evident that we cannot have men-of-war enough to protect all our commerce. The question of convoys has lately been spoken about. I forget the number of and tonnage of the sailing ships in the merchant fleet; nobody would take the trouble of convoying them, and I believe they will not go to sea when we are at war with a maritime nation. They would not take very long voyages, and if they did no one would put their goods in them. Therefore we need not consider the question of sailing ships at all. Slow steamers would also be at a discount, but they would have to be employed. Grain, coal, and a variety of other cargoes would have to be carried outwards or inwards, and the slow steamers, which could hardly be armed, or not necessarily armed, would be such a drag upon the convoy that you could not attempt to convoy them. What you can do is this: The insurance offices might take care that the ships should proceed by certain routes, and those routes must be patrolled. I suppose we are to have an Intelligence Department, and the first thing that will have to be known is how many ships the enemy has; who the enemy is, first of all, and how many ships he has. The duty of our men-of-war will be to bottle our enemy's ships in harbour if possible; and it will also be the duty of the

Intelligence Department to ascertain what ships have escaped, and what sized ships they are. We must take care that if they are heavy men-of-war there must be heavy men-of-war to meet them. There must be a sufficient number of ships to guard them on the lines to be traversed. There will be a vast number of light, fast cruisers, which will be sent out to cut up our commerce, and our lines must be patrolled by this class of valuable armed merchant ships, which will be able to overhaul any of these cruisers—or privateers, if you like to call them by that name—and capture them, or, at any rate, prevent them from going into any port where they can obtain coal. I should be going out of my way if I were to say that the protection of our coaling stations is a necessary corollary to arming these merchant ships. They must have an abundant coal supply for themselves, and they must have force enough to prevent the vessels of the enemy from obtaining that coal supply. The lecturer has alluded to the loss of the *Oregon*. It certainly has given a caution, I think, to shipowners and to others to take care that the vessels which are proposed to be used for this purpose have the longitudinal bulkhead and the twin screw, in addition to an ample coal supply and great speed. I cannot too much urge upon the meeting the necessity, above all things, for speed in our men-of-war. I look upon those two splendid ships, the *Trafalgar* and the *Nile*, perhaps, with different eyes from the lecturer. I admire them excessively; but I would have made some sacrifice to have obtained a speed in those ships which would have enabled them to overtake the *Italia* and the *Lepanto*, and other vessels of the Italian Government. The *Italia* has a speed of eighteen knots an hour, which has been kept up for forty-eight hours consecutively; and as I read the return of what was expected from the *Trafalgar* and the *Nile*, they do not reach that speed. Indeed, we have no protected armoured ship which could catch any of those ships, or keep up with them, or run away from them, or do anything with them at all. The want of speed is therefore a very serious question; but I cannot too much urge upon this meeting my belief, as a Naval Officer, that really the first quality, after seaworthiness, is speed; and some sacrifices, perhaps, may have to be made for this purpose. In these vessels we are to have the greatest speed, and as I understand their duty will be to patrol the great lines of navigation, and to give that protection to our merchant ships which formerly they derived from convoys, and which now they must derive, like the ordinary passengers of the street, from these police of the sea.

Captain C. C. P. FitzGerald, R.N. (Associate): I have been invited to offer a few remarks upon this paper, my Lord, as a Naval Officer. I may say that in the general tenour of Sir Nathaniel Barnaby's contentions, I entirely agree as to the closer connection between the Royal Navy and the Mercantile Marine before war breaks out, as I quite think that all organisations should be made before the event, and we should then avoid such panics as we saw the other day when there was a probability of war with Russia. Although I do not agree in all the details which have been brought forward, I think we might, by a better organisation, put the subject under the care of the Intelligence Department, which is quite competent to deal with it. There is one point which Sir Nathaniel Barnaby has mentioned to which I wish to draw attention. He says: "A fast mail or passenger steamer may be as efficient a factor in a naval war as an ordinary war cruiser, which has cost a quarter of a million sterling, and has a crew of five hundred or six hundred men." I should say that a "fast mail or passenger steamer," in order to be "as efficient a factor in a naval war as an ordinary war cruiser" in time of war, would cost a quarter of a million herself, or something very near it. Our cruisers certainly do not carry crews of five or six hundred men, and I should imagine they would not in the future carry more than two hundred at the outside; but that is merely a minor point of the subject, on which I will not dwell. Another point to which I should like to draw your attention is this. Sir Nathaniel Barnaby says: "Without organisation, ships of the highest speed, and carefully

built, may be found at time of need, when the Commander-in-Chief on a foreign station imperatively needs their services, to have not a single trained officer or seaman on board." Then he says that "Thousands of Royal Reserve men may be found in ships having no defensive power whatever, and none in the ships which have so high a value." I am not aware whether the question that is raised here is one which has been fully considered. Supposing one of these mercantile ships is found on the station when a war breaks out. She would have no guns in her. She might perhaps have the proper amount of Naval Reserve men, but, if I understand rightly, these ships are not to carry their guns. It will be necessary, therefore, that they should come home to England in order to be regularly commissioned as men-of-war. Privateering has been done away with, if I am correctly informed, and we should have to come to some conclusion as to whether those ships were to be *bonâ fide* men-of-war, commanded by Naval officers, or whether the captain of the ship, with his proportion of Naval Reserve men, is to say: "I am a fighting ship. I am going to get my guns from Bermuda or elsewhere, and I am going to fight." I doubt if that would be legal, and whether that is a policy we can pursue now-a-days. If not, the ship would have to come home, and to be properly commissioned. As to the question of want of bulkheads, that is a subject I do not know much about. Sir Nathaniel Barnaby says the ships are not fitted with proper bulkheads to prevent them from sinking. If so, would not that be a matter for the underwriters? Why do the underwriters insure ships that are not properly fitted? I was under the impression that if a ship was not considered seaworthy she would not be insured. Sir Nathaniel Barnaby points out something of the hardships attendant on life on board merchant ships, and if I understood him correctly, he proposed that certain regulations should be made to better the condition of seamen. I imagine that it is simply a question of pay, and a matter of political economy, and that you get a class of men corresponding to the price you choose to pay, and I should deprecate any artificial interference with supply and demand. I may say that the proposition that the management of the Mercantile Marine and the Royal Navy should be brought under one arbitrary head, is a point on which I disagree. Rules would be made for the Mercantile Marine such as I imagine they would not stand. It would fetter trade to such an extent that it would tend to crush out the splendid development of enterprise we see in this country, where we go for the best market, and can hold our own to a certain extent against foreign competition. I should say that it would crush out the life of our mercantile enterprise, to have the trade of the country put under hard and fast rules, and put under the immediate control of the Admiralty. Sir Nathaniel Barnaby also points to what we might call "the dim and distant courses of the future." He says: "It is conceivable that steel ships will be built richer and more populous than many a famous English town—ships not only carrying for traders, but trading on their own account, and providing for permanent residence as well as transport. Such ships must be armed and garrisoned, and must unite the mercantile and military elements within themselves." I must say I can hardly imagine what you might call an armed pedlar's shop going about the world and doing any successful business. The general idea of trade is to land your cargo as fast as you can, and come back for another one. I have one observation to make on Admiral Sir John Hay's remarks in reference to the coaling stations. Undoubtedly that seems to be the key to the whole question. If we can protect our coaling stations we can protect our trade routes. The enemy's cruisers would be perfectly useless unless they could get coal. I believe they can get coal to a certain extent at neutral ports, enough to carry them to the next port, but if we can watch those neutral ports we do not want to watch the trade routes. If we can watch the neutral coaling stations, and bottle the ships up there, we need not watch the trade routes. With respect to the remarks concerning the *Italia* and the *Trafalgar*, Sir John Hay pointed out that the *Italia* had superior speed to the *Trafalgar*, and he says that sacrifices ought

to be made to get high speed. I for one think that high speed is of the very greatest consequence, but at what sacrifice? He says the *Trafalgar* would neither be able to catch the *Italia* nor get away from her. That is true, but the *Italia* is not an ironclad at all. She is a tin kettle. Any ship could sink her with popguns. She has no water-line armour. You could sink her with six-pounders. She is a very good ship to run away, I admit. I think we have already gone in the direction of denuding our ships of their armour to such an extent that they are not fit to cope with some of the ships of our possible enemies on the Continent. They have superior speed, and therefore they can run away, but that has not hitherto been our national policy, and I should be very sorry to see it become our policy, by reason of our ships being so constructed, that almost all fighting efficiency was sacrificed to speed.

Mr. W. H. White (Vice-President): My Lord, I think it would be a great pity that this discussion should now terminate; and I know that there are several Naval men present, besides Captain FitzGerald, who might well instruct us on many points that have been raised in the paper. I hope, too, we may have the pleasure of hearing the views of those who represent "Lloyd's Register," as to the proposed extension of their functions in relation to the Mercantile Marine. But leaving those matters apart, we, who know the many years' constant thought and constant effort which Sir Nathaniel Barnaby has devoted to the consideration of this question, although we may differ from him in many points, cannot but respect the conclusions which he has reached. There are many points in this paper as to which I do not agree with him. There are some which are purely speculative, such as the future floating city to which Captain FitzGerald has referred. I think that, within our lifetime at least, even if the history of ship construction be continued by "leaps and bounds," we shall scarcely reach that stage of development. It appears to me that the commercial marine must always find its natural development in commercial conditions and commercial success, and that the utilisation of the undoubted force which resides in the Mercantile Marine for the purposes of national defence, must be subordinated to commercial considerations. The shipowners of this country, in my judgment, have, during the last ten years, shown a broad and generous spirit in the adaptation of their vessels more and more to what may be called Imperial requirements; and I can only say, speaking for myself, and in no way as an official, but as a private individual, that I am heartily glad that at last there has come a time when the law of "something for nothing" is recognised by the Government of this country as one that cannot continue in this matter. The shipowners of the country have been asked, for ten years past, to develop certain features in their ships, but, until now, I am not aware that they have had any compensation whatever. This is the first step which has been taken: it may have been long delayed; on that matter Sir Nathaniel Barnaby has spoken strongly, but I express no opinion. But this first step which has now been taken, in giving to some shipowners of the country a retaining fee in order that their vessels may be at the service of the State, is a distinct step in advance; and I hope sincerely that it will be followed by other steps in the same direction. For there can be no doubt that money spent in that way can only be well spent. The fact is very important in considering the possible uses of our own merchant ships in war time. I am not pretending to say what is their best employment in war; but, to whatever use they may be put, this is to be remembered. In recent years, foreign mercantile navies have been adding to their fleets vessels of great speed and high qualities, and have been competing with the English Mercantile Marine, in this class of ships, in a way which was formerly, and until lately, quite unknown. We have the pleasure of having present here to-day a gentleman who has done, in France, for the great French Steamship Company with which he is connected, a work which will result in the addition to their fleet of vessels that will compare favourably with anything which we

possess. In Italy, the same course is being followed; and in Germany, as we know well, the same course is also being followed. That is to say, while the English Mercantile Marine, through its very supremacy in numbers and in value, continues to be our great source of advantage and profit in time of peace, and our great danger and possible weakness in time of war, there are increasing all about us—and we cannot shut our eyes to the fact—the means of attack upon that Mercantile Marine. And I think, without speculating as to who may be our enemies and who our friends in any future struggle, it cannot but be regarded as sound policy that the fullest thought should be given to the utilisation of the mercantile ships of this country, as protectors of our own Mercantile Marine in time of war, against the attacks of improvised cruisers. I, personally, am strongly of opinion that it is not merely the very fast ships which will be of value to us, but also vessels of moderate speed, which carry, with that moderate speed, enormous coal endurance. Those who have studied the history of the *Alabama* cannot fail to have noticed that it was her slight advantage in speed, and certainty of operation, that made her a terror to the then Mercantile Marine of the United States, which was composed almost entirely of sailing vessels. I presume that we must now, as a matter of course, regard our sailing ships as practically impossible of complete protection from privateers. But a vessel of moderate speed, lightly armed, and with large coal endurance, would stand in much the same relation to the great bulk of the mercantile steamers of this country, at the present day, that the *Alabama* did to the sailing ships of the United States twenty-seven or twenty-eight years ago. And, I say again, independently of whether it is a proper subject for this Institution or not, that we, as Englishmen, must be glad that we have, at last, taken a step which shows a beginning in the way of organisation, and that we have, not only the facts stated by Sir Nathaniel Barnaby, but also important further details in recent Parliamentary papers on the subvention of merchant ships. Statements have been made in Parliament by the First Lord of the Admiralty (Lord George Hamilton) and Lord Charles Beresford, as to what steps have been taken with regard to organisation, and there is now, in fact, a frank recognition of the necessity for action, and a readiness to take that action, at which, I think, we must unfeignedly rejoice.

Admiral A. F. R. De Horsey (Associate): Your Lordship has been good enough to call upon me, but I think I have very little to add to what my brother officer (Captain FitzGerald) has said, I so entirely agree with his observations. I have read Sir Nathaniel Barnaby's paper with great interest, and I agree on a good many points, but perhaps he goes too far in the matter. I think that the First Lord of the Admiralty would hardly consent to pay for all the first-class merchant ships of England, however satisfactory such a course might be to the companies that own them. We must also take care not to neglect to keep up the strength of the Navy in the hope of making use of these vessels as war-ships when war occurs. I quite agree with Sir Nathaniel Barnaby that these vessels would be most valuable. But wars break out very suddenly, and I think it has been overlooked that a war might be half over, or even terminated, before you could bring these vessels into full swing. They would be abroad; they would be full of cargo; they would be in all parts of the world. It is true it is proposed that they should be fitted to carry guns, but we all know it is one thing to have a vessel nominally fitted, and it is another thing to have the fittings complete, maintained fit for service. I do not believe myself that one of these fine large steamers coming home from her carrying trade abroad would be ready for service within a month. I should like also to say a word on the point of speed, which my gallant brother officer, Sir John Hay, has spoken of. I agree with him that speed is a very good thing, but I also strongly agree with Captain FitzGerald that in itself it is not everything, neither is it in my opinion by any means the first necessity for a fighting ship. Speed is most valuable to catch an enemy, but in order to have excessive speed we must sacrifice something else, and what is

the use of catching your enemy if you cannot fight him when you have come up with him? Speed is admirable for running away, but, as has been well said, we hope not to do that. We must not forget that ships are compromises. We try to get the utmost speed, the utmost power of guns, the utmost defensive armour, the utmost coal capacity; the whole thing is a compromise, and if we put so much stress upon that one element, speed, we shall be apt to neglect other and still more necessary qualities. As I have said, it would be of no use to come up with your enemy unless you can fight him when you get there. I am very much pleased, and I am sure all my brother officers are, to see the move which has been taken by the Admiralty to secure the services of these valuable ships in case of war; but I would urge, that our efforts to bring our Navy proper up to an adequate strength should not on that account be diminished. Our Navy must be kept sufficiently strong to make us safe from attack, and let us not trust to the assistance of merchant ships, which we may only be able to obtain when it is too late, and which in any case cannot be proper fighting ships. I wish to say one word more upon a minor matter. I cannot agree with Sir Nathaniel Barnaby that it would be well to place one Secretary of State for the Navy over the Admiralty and also over all the mercantile shipping of England. I cannot conceive anything more incongruous. The duties are utterly different. The Admiralty have already as much as ever they can possibly do in looking after their present charge, and I think it would be beyond the power of any single man to rule the Merchant Navy of England and the Royal Navy; nor do I think that the shipowners of England would be best pleased to find their interests subordinated, as they would be, to those of the Royal Navy.

Mr. B. Martell (Vice-President): My Lord, I have only a few words to say upon this subject. This paper deals with a question of such great importance that any light whatever that can be thrown upon it must be of value. Now, I think that the action of the Admiralty for many years past has been highly reprehensible. I have heard very many opinions expressed on their action and on their policy which I entirely agree with. Let me state what I mean. For a great many years past they have had a staff, members of which have been travelling through the country, at various times, inducing shipowners of large ships to go to very considerable expense in fitting bulkheads to comply with certain requirements of the Admiralty; and the inducement which has been held out to them has been that they would ultimately reap some reward for the expense that they might incur. I know that many ships have been fitted at great expense to comply with these requirements of the Admiralty. Well, now, what reward have they received? During the Egyptian War, when there were a large number of ships of the Mercantile Marine lying in dock, and could have been chartered by the Government, fitted in the manner I have described, with all the bulkheads and all the requirements of the Admiralty, what did the Admiralty do? Instead of rewarding the shipowners who had gone to the expense of fitting their ships in accordance with the requirements of the Admiralty, they almost invariably chartered ships which had not fulfilled such requirements in any way whatever. I maintain that that was breaking faith with the shipowners of this country. I have no doubt that very great benefit would have been derived had the Admiralty only acted in a just manner towards those owners who had complied with their requirements, because many other owners would have been induced also to comply with the same requirements, and would, in the same way as Sir Nathaniel Barnaby alludes to, have strengthened the hands of the registration societies. I think, therefore, the time has come that some more definite action should be taken by the Admiralty in this matter, and I am very pleased indeed to see the action that is being taken by the present Admiralty. I think that the money may very well be spared which will ensure that some of these ships may be ready at a time of war, when they may be required. After seeing some of these fine ships fitted up as auxiliaries—I allude to those that were taken up for this purpose during the last war—and seeing the guns that were placed on board, I am

quite sure that in time of war they would be found most efficient auxiliaries to the Royal Navy generally. Now, I have only one word more to say, and that is, to thank Sir Nathaniel Barnaby for the very high estimation in which he appears to hold the Registration Society. On the part of that Society I beg to return my most sincere thanks, and I can only say that should extended powers be given to it, as suggested by him, I am quite sure that Society would be quite ready to accept them, and I have every reason to believe would perform their functions in a most satisfactory manner. In saying this I should like to make it clear that I was not in any way made acquainted with Sir Nathaniel Barnaby's views in this matter in putting this forward. I can only repeat, however, that if it be thought that the Committee of Lloyd's Register Society could in any way assist in a scheme for supplementing the strength of the Royal Navy with efficient mercantile ships, as shadowed forth by Sir Nathaniel Barnaby, I am strongly of opinion that they would willingly render such assistance as might be within their power.

Mr. H. H. West (Member of Council): My Lord, I may say that I approach this subject as a layman. About war-ships I know little or nothing, but it appears to me that if there is use for merchant ships as fighting ships, there is use not only for fast ships, but also for slow ships. As Captain FitzGerald has said, the use of speed in a great measure is, having the power to run away, and that is a thing which, as he very properly says, we do not want to do. Possibly slow ships, if armed, might be able to fight—as far as mere fighting is concerned—as well as fast armed ships, and possibly—I am speaking quite as a layman—some of the duties of convoy, of which Sir John Hay speaks as a thing of the past, might be done by slow ships where the convoyed ships were all of about the same moderate speed. But to pass from that point: Sir Nathaniel Barnaby lays great stress on subdivision. Now, with regard to subdivision, there are many points that come up bearing upon merchant steamers. I am one of those who are heterodox enough not to believe in water-tight doors. I have somehow or another got it into my head that a water-tight door when it is wanted to be water-tight is pretty sure not to be workable, and that a bulkhead with a hole in it, even if it has a so-called water-tight door, ceases to be a trustworthy water-tight division. Now, there are water-tight doors that have been contrived (I schemed one myself at one time, but did not make a great deal of it) by which a large water-tight cell, of any convenient size, is made to form a part of the bulkhead, and into this cell, on opposite sides of it, two water-tight doors are fitted, so arranged as that one cannot be opened until the other is closed; so that, while there is a free passage through the bulkhead, one or other of the doors is always closed water-tight, thus keeping the bulkhead intact—much on the principle of the doors that are fitted to the air-lock of a stoke-hole with forced draught. By that means I think it is possible to make a water-tight door that would answer the purpose. It has occurred to me also that an advantage would arise from closing the door upwards, instead of downwards wherever there is space enough below the opening to allow the door to travel upwards. I believe the door would be found to work more safely and to keep in better working order sliding upwards than downwards. There is one difficulty about the subdivision which I wish to allude to, and that is a matter which is associated with the very important question of freeboard. Now, a merchant steamer to be a commercial success must be loaded as deep as it is reasonably safe to load her. That being so, the size of each compartment is limited by the amount of freeboard of the ship, and if we are effectually to subdivide merchant steamers of low freeboard, we must necessarily have small compartments, and if we have small compartments we must necessarily have, from the commercial point of view, exceedingly inconvenient ships for carrying our goods. That point seems to me an important one in any consideration of the subject of the use of purely cargo ships for such purposes as Sir Nathaniel Barnaby brings before us in his paper. I do not know, my Lord, that there is anything

more that I have to say. I have listened to the paper with very great interest, and I am sure we are much indebted to Sir Nathaniel Barnaby for bringing it before us. There was one little matter that did occur to me, and that was the question of continuous double bottoms. That is a type of vessel which is now becoming very popular amongst shipowners, and I think it must be an advantage to any vessels that are employed as armed cruisers that they should have the bottom so constructed that there is no danger of the ship sinking because of damage to her outer bottom plating. If that is continued so far to the ends that the remaining part is small in comparison with the whole mass of displacement, and is effectually bulkheaded, I think it would be an undoubted advantage.

Mr. S. Barnaby (Member): My Lord, there is one remark in the paper which I should like to refer to. It is this: "A fast mail or passenger steamer may be as efficient a factor in a naval war as an ordinary war cruiser which has cost a quarter of a million sterling." Captain FitzGerald asked the question whether the mail steamer would not also cost a quarter of a million sterling, and I gathered that the conclusion he would draw would be that the quarter of a million was expended better in the ship built for fighting purposes than in the merchant ship. (Captain FitzGerald: "Certainly!") I think there was one point he overlooked. The quarter of a million expended in the merchant ship is productive of interest independent altogether of its potential fighting capacity, whereas the quarter of a million expended on a war-ship, pure and simple, gets no interest whatever, and is subject to a very high rate of depreciation, not only on account of the wear and tear, but also on account of the rapidity with which it becomes obsolete as a fighting machine. Therefore, I think that if the merchant ship for any service can possess equal capabilities with the war-ship, the quarter of a million is better expended in her production. I think Sir Nathaniel Barnaby is quite of opinion that it is not advisable to hamper in any way the merchant shipbuilder, or to handicap him in competition with the foreign merchant ships. All he would ask them would be to do what they can, having clearly in view that they must not handicap themselves, and that it is necessary for the Government to subsidise to such an extent as will recoup them for the extra expenditure incurred in the building of the ship. I think that is all I have to say.

Sir Nathaniel Barnaby (Vice-President): My Lord and Gentlemen, I do not purpose to trouble you with many remarks in replying upon this paper, but I should like to make myself clear at once on a point which has been raised by our friend Captain FitzGerald, and also by Admiral De Horsey. Captain FitzGerald said that I had proposed to put the Mercantile Marine under the control of the Admiralty. It was the furthest thing possible from my thoughts. Admiral De Horsey also talked about the Mercantile Marine being subordinated to the Admiralty. Some misconception is to be found there. I never suggested that. What I say is this: there are identical interests to a large extent in those two great sections of our vast national Marine; and instead of the Marine Department of the Board of Trade being a section merely of the great trade department, it should be allied with the Admiralty—not put under it in any sense, nor the Admiralty put under it, but there should be a Secretary of State over those two great marine departments. It seems to me that it would work as well and as smoothly, so far as official work is concerned, as the Marine Department of the Board of Trade may be now expected to work, with the other departments of the Board of Trade, all of which are presided over by one head. But that the shipbuilding industry of this country should be fettered in any way by the Government is a thing which is totally opposed to my views. In fact, I have stated here clearly, that I consider it would be far better that a large amount of the work which is now done by the Government should be done by private persons, and by these voluntary associations of which I have spoken, who would give the country, as I believe, far better results than they can get now by

the interference of the Government. In saying that, I know I am taking the same view as is taken by Sir Thomas Farrar himself in the book he has written on the subject,* with which I quite agree. He points out the difficulties connected with the interference of the Government with the free action of shipbuilders and shipowners. Having, as I hope, made myself clear on that point, I would say a word with regard to a question which Captain FitzGerald always raises when I have the pleasure of seeing him. I am sorry to find that his recent sea voyage has not converted him at all. That is, as to the question of side armour. There is an interesting paper to be read here on Friday, and Captain FitzGerald will then have an opportunity of saying what he has at heart on that subject, and those who wish to debate the question of what is the use of the *Italia*, will no doubt find ample opportunity for doing so. It was said that five hundred or six hundred men was a very large crew for an unarmoured man-of-war cruiser. That is true, but there are still many ships which have that number. Captain FitzGerald knows that.

Captain FitzGerald: They are obsolete.

Sir Nathaniel Barnaby: They are in existence and flying the Queen's flag to-day, in different parts of the world. He knows their names as well as I do. It is all very well to call them obsolete, but they would have to fight if there were a war. I think, my Lord, that after these remarks I have nothing further to do but to thank the gentlemen who have been good enough to criticise my paper.

The President: Gentlemen, I have on your behalf to thank Sir Nathaniel Barnaby for his valuable and interesting paper, and for the discussion which has ensued.

* "The State in its Relation to Trade."

COMMUNICATION RELATING TO THE RESULTS OF A SERIES OF PROGRESSIVE TRIALS CARRIED OUT AT CHERBOURG ON A TORPEDO BOAT.

By Mons. L. De Bussy, Honorary Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 30th, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The object of this communication is not to place before the Institution any novel facts, but to add to its stock of information, by putting it in possession of the results obtained, while subjecting a torpedo boat belonging to our national Marine to a series of trials, carried out at progressively increasing speeds, in which the excellent method so frequently employed by the late Mr. W. Denny was followed, the advantages of which have been put in evidence by many interesting papers contributed by different members, and notably by that of W. H. White, Esq., Director of Naval Construction, "On the Speed Trials of Recent War-ships" (Transactions, vol. xxvii. pages 1—12).

Being desirous of emphasising the importance which the French Constructors attach to this fertile method of experimenting, the author thought that it would be agreeable to this Institution if he obtained from the Minister of Marine the authorisation to communicate the results of the trials in question, which were obtained at Cherbourg on a torpedo boat, 33 metres (108 ft.) in length, constructed by Mr. A. Normand, of Havre.

The formula which is made use of in France to determine the speed corresponding to a given power is

$$v = m \sqrt[3]{\frac{\text{I.H.P.}}{B^2}}$$

where

v is the speed in knots.
B^2 the area of the midship section in square metres.
m the co-efficient of efficiency, which had to be determined for the various speeds.

The experiments were all carried out on the same day, in identical circumstances of weather, sea, and draught of water. Each of the results is the mean of three runs on the measured distance. In order to eliminate the influence of the variation of the

current, the figures obtained on the intermediate run were doubled. Thus were obtained the results given in the following table, which are given exactly as they were got, and without any correction.

Speed in Knots. v. (1)	Number of Revolutions per Minute. (2)	Horse-power Indicated on the Pistons. I.H.P. (3)	Values of $m = v\sqrt[3]{\frac{B^2}{\text{I.H.P.}}}$		Observations.
			Taking the Square Metre as the Unit of Surface. (4)	Taking the Square Foot as the Unit of Surface. (5)	
4·7	64·15	9·33	2·863	6·322	The value of B^2,
8·91	126·16	42·44	3·276	7·233	or the immersed
10·20	145·73	62·19	3·302	7·307	area of midship
10·94	157·99	67·33	3·449	7·615	section, is 2·11
12·89	186·57	120·93	3·343	7·381	square metres, or
14·58	215·37	184·23	3·286	7·256	22 square feet.
16·80	253·97	300·58	3·216	7·102	The displace-
18·20	275·68	377·40	3·230	7·132	ment is 46·10
19·30	293·32	443·65	3·242	7·159	tons.

An examination of this table reveals two interesting peculiarities :—

1. The value of m, which is very small at low speeds, increases up to 11 knots.
2. This value attains a minimum at 17 knots, and increases slightly for higher speeds.

The first peculiarity must no doubt be attributed to the fact that the efficiency of the engine, in mechanical work on the shaft, diminishes in proportion as the speed of revolution is decreased. It cannot be doubted that if the power actually transmitted to the screw, instead of that indicated on the pistons, could be introduced into the formula, the efficiency measured by the co-efficient m would be greatest at the low speeds. This first peculiarity, then, appears to proceed from circumstances inherent in the motor. The second, on the contrary, evidences a diminution in the resistance of the hull when a certain speed is exceeded, and is, in consequence, particularly worthy of attention.

DISCUSSION.

Mr. A. Spyer (Member): My Lord and Gentlemen, I venture to think that the facts recorded in this paper by M. de Bussy are of great interest and of considerable importance; and they afford an interesting subject of professional discussion at this Institution, giving as they do technical information of much value. Some six or seven years ago the Admiralty carried out a somewhat similar series of experimental trials with a torpedo boat 86 feet in length, a rather shorter boat than the one alluded to here by M. de Bussy. The results obtained on those trials were very noticeable, and to a considerable extent confirmed some of the peculiarities to which M. de Bussy has called attention here. The whole of the trials were carried out twice over, in order to avoid any doubt as to the results which were obtained. The effect was, so far as regards the second peculiarity to which M. de Bussy has called attention, to confirm it absolutely, the high efficiency alluded to being obtained at a somewhat lower speed corresponding to the length of the boat. In fact, in an 86 ft. boat, going from 16 to 18 knots, we found that the I.H.P. was only increasing something like the 1·7th power of the speed, whereas in going from 13 to 15 knots the I.H.P. was increasing as the 4·1 power of the speed. Here with an 86 ft. boat, at about 16 knots speed, we found the same increased efficiency which M. de Bussy has shown to exist at a corresponding higher speed of 17 knots in the longer boat. With reference to the second peculiarity to which M. de Bussy called attention, if criticism may be allowed upon the statement of so eminent an authority, I would venture to think it is somewhat doubtful whether the efficiency of the engine and the screw would cause the abnormal result at 11 knots pointed out by M. de Bussy. For these high speed propellers in torpedo boats I rather fancy that the efficiency would be found to decrease with the speed of revolution in a fairly uniform manner. I obtained this paper a few moments before it was read, and jotted down M. de Bussy's results in the form of a speed curve, and found so remarkable a hump in the curve at the low speed of 10 knots, extending over such a short length of the curve, that I feel disposed to think that this is possibly due—I do not say absolutely, I throw it out as a suggestion—to some inaccuracy in the records obtained. At all events at so low a speed this peculiarity would hardly have been anticipated. Perhaps it would be as well if I showed you what I mean on the blackboard [indicating on the board]. This is a very meagre sketch, but in the diagrams made for the 86 ft. torpedo boat we found in going from 16 to 18 knots the I.H.P. curve roughly took the form which I have indicated here. M. de Bussy has shown practically the same result, only at somewhat higher speed, as one might expect from the length of the boat, and at a speed of about 17 knots. I venture to doubt the existence of what his figures give, which is something like this [illustrating], for the low speed of 11 knots. It may be so, but I would merely suggest that there may be perhaps a little doubt about the figures which cause such a very peculiar occurrence. In conclusion, I would remark that we all recognise the value of the paper, and would thank M. de Bussy for sending to us such valuable information, which, coming as it does, from a foreign member of distinction, is received with exceptional pleasure by the Members of this Institution.

Mr. J. I. Thornycroft (Member of Council): My Lord and Gentlemen, the subject is of great interest to me, but not quite new. In a paper read before this Institution in 1872 by Sir F. Bramwell, the variation in co-efficient of performance for different speeds of the *Miranda* shows with increase of speed, first a reduction, and afterwards an increase in the value of the co-efficient; and I may say further, that the small irregularity of outline of the curve referred to is merely an illustration of the effect of the bow wave when falling in the wake which has been so admirably experimented on by Mr. Edmund Froude, who has shown that the rate at which the resistance increases constantly varies, and it is an irregular curve even from a comparatively small speed. I am sure we all thank M.

de Bussy very much for bringing this subject before the Institution, because the records of trials giving details in this way are really of great interest, and I would tender my thanks for this having been brought before us.

Mr. W. H. White (Vice-President): My Lord, I have in my hands some notes of the experiments made by the late Mr. Froude on a model of the *Lightning*, which was the first of the 86 ft. torpedo boats built for the English service. In these experiments there was no question at all about the influence on the performance of the vessel of the action of the propeller, but simply a determination of the "tow-rope" resistance. What was discovered was this: that up to 10 knots speed in a boat 86 ft. long, the resistance varied very nearly as the *square* of the speed. At about 13 knots the resistance was varying as the *three and four-tenths* power of the speed. But when speeds from 16 knots to 19 knots were reached, then the resistance was varying about as the $1\frac{1}{2}$ power of the speed. In order to gain a knot from 13 knots to 14 knots, an addition was required, speaking roughly, of something like 25 to 30 per cent. of the power which sufficed for 13 knots: to gain a knot from 10 to 11 knots, the corresponding percentage of increment was about 20; and to gain a knot from 17 to 18 knots, required say only an increment of about 10 per cent. The results obtained from Mr. Thornycroft's *Miranda*, and also by experiments which Mr. Yarrow made on a boat about 100 feet long, curiously confirmed Mr. Froude's experiments with models. When a speed of 20 knots or thereabouts was obtained in Mr. Yarrow's boat, the law of resistance was considerably lower in its index than at lower speeds. The explanation of this circumstance is to be found most fully set out in Mr. Edmund Froude's paper published a few years ago in our Transactions on "The Waves that accompany the Motion of Vessels at High Speed," these experiments having also been made on models of torpedo boats. I do not understand that M. de Bussy so much announces a discovery as that he confirms by his experience the results which previous investigators had reached, and I am sure that we are greatly obliged to him for the facts that he gives us, because my experience in matters of steamship propulsion is that the main thing is to get the facts, and you can generally get the explanation afterwards, especially of circumstances such as those I have mentioned, which may be most difficult to anticipate.

The President: Gentlemen, I do not want of course to stand in the way of anybody wishing to speak to the paper, but as I do not see anybody rising, I am sure you will permit me on your behalf to thank M. de Bussy for his paper; it is the result of experience, which is always of the greatest value. As coming from one of our foreign members, we value it even more highly. Communications of this kind must always assist the cause of science, and lead ultimately to the truth. I must explain to you that M. de Bussy does not know English quite as well as I do; I wish I knew French as well as he does; and he is not able, or rather does not feel himself quite capable of replying upon his paper, and with that explanation I am sure you will allow me to tender our united thanks to M. de Bussy.

TWIN-SCREW TORPEDO VESSELS "WIBORG" AND "DESTRUCTOR."

By J. H. Biles, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

I venture to lay before this Institution a short description of two torpedo vessels which have each some features in them not common to vessels of this class.

The *Wiborg* was built at Clydebank for the Russian Government. The general particulars are given at the end of this paper. The conditions laid down to us were:—

(1) Speed to be 20 knots per hour upon two trials, each of three hours' duration.

(2) The weights on board at these trials to be a load of 15 tons, representing armament, torpedoes, stores, men and equipment, and an additional 14 tons of coal, or 29 tons in all.

(3) Between the two full-speed trials a consumption trial of 12 hours' duration to be made, to show that, with the trial weight as above on board, the vessel could steam 1,200 knots at a speed of not less than 10 knots per hour.

(4) The armament to consist of two 5-barrelled Hotchkiss 47-mm. revolving cannon, with 500 rounds of ammunition to each gun.

(5) The torpedo tubes to be three in number, two through the bow and one on deck, each 19 ft. long.

(6) Metacentric height to be not less than 1·75 ft.

(7) The pumping power to be sufficient to eject at least 520 tons of water per hour, independently of the pumps for surface condensers.

(8) The bunker capacity to be sufficient to give vessel a radius of action of at least 2,000 knots at 10 knots.

The dimensions selected to fulfil these conditions were:—Length on water-line, 142 ft.; beam moulded, 17 ft.; depth at middle of deck, 9 ft. 6 in. In fixing these dimensions the following considerations were kept in view:—

1st.—The torpedo boat fighting tactics of the Russian officers were said then to

consist of a run straight at the enemy at full speed to within 700 yards, when the engines were suddenly to be reversed, and the bow torpedoes fired as soon as way was off the vessel. As rapid a retreat as possible was then to be made at full speed astern.

2nd.—The vessel was intended to act against a fleet of hostile torpedo boats, and must, therefore, be prepared to receive a much greater number of wounds from small guns than these boats could each receive.

3rd.—As her radius of action was much greater than that of torpedo boats, her habitability ought to be increased, and made as nearly as possible equal to that of an ordinary cruiser with the same radius of action.

The first consideration made it desirable to protect the bow torpedo tubes from machine-gun fire as much as possible. This end was attained by giving the vessel the long sloping bow shown in Plate XVI., and by covering this bow with plating ¼-inch thick. To ensure rapid reversal of engines steam starting gear was fitted, a course seldom adopted in such small engines. In order to ensure capability of steering when running considerable distances at full speed astern the rudder and the after part were shaped as shown in the drawings.

The second consideration pointed to as minute a subdivision of hull, and as complete a duplication of vital powers, as was possible. Consequently, twin engines and twin boilers were adopted, though both were in this type of vessel a novelty. The boilers are in separate water-tight compartments, but it was considered desirable in such a small vessel, with her limited crew, not to add to the difficulties of looking after the machinery by placing a bulkhead between the engines. The vessel is divided into twenty-three compartments. The alteration of trim due to flooding some of the largest compartments is shown on Plate XVII. To still further enable the vessel to maintain her fighting capabilities with as many wounds as possible in her, the side in the vicinity of the water-line in the crew compartment forward, which is the largest in the ship and which is most likely to be penetrated when attacking an enemy, has a double water-tight skin. This double skin is subdivided into cells by small transverse bulkheads, which cells can be fitted with water-excluding substance, so that in the vicinity of the water-line the largest compartment of the vessel has what is practically a coffer-dam round her side. The engines and boilers have protection afforded them by the coal bunkers, which completely surround them. The magazine is placed well below the water-line. The pumping power in the vessel is an element in the quality of her capability to receive without fatal results a large number of wounds. She has ten ejectors, capable of discharging 1,500 tons of water in all per hour; and her two centrifugals are capable, in addition, of discharging about 300 tons per hour. In order to make use of this pumping power the boilers would have to be fed from the

sea, but their capability of raising steam is far more than equal to the demand which would be made by these ejectors.

The third condition, as to habitability, can only be decided by reference to the vessel's behaviour at sea. But it is certain that it is necessary to give a sufficient amount of deck space and cubic capacity per man in the living quarters. The total complement of the boat is 22, four of whom are officers, and are accommodated in the after part. The clear deck area per man for the 18 men is 9 square feet, and the space per man is 120 cubic feet. The living compartments are placed in communication with the forced draught fans, so that as long as the stokehole ventilators can be kept open, these compartments can be well ventilated. But these are, I venture to think, nearly all that a ship designer can do in a vessel of this type. The condition of lightness of hull and machinery which must be fulfilled in order to obtain the high speed desired, taken in conjunction with the conditions as to subdivision and habitability already mentioned, make the percentage of surplus buoyancy very high, and consequently a vessel of this character is very lively in her motions. This liveliness is not compatible with comfort, and consequently tends to detract from the habitability of the vessel. The results of the consumption trial showed, that with the 45 tons of coal which the bunkers would hold, the vessel had a radius of action of over 4,000 knots. The results of her behaviour at sea, as reported by her commander, showed that she could safely go through heavy weather, but whether her crew could remain in working condition long enough to traverse 4,000 knots at 10 knots, which would be about 17 days, can only be determined by continued trial.

On her speed trials, details of which are given at the end of this paper, she attained 19·96 knots with nearly 41 tons weight on board, and she attained 20·6 knots with nearly 34 tons weight. These speeds are the mean of the speed on the three hours' runs as deduced from the revolutions. At a later trial with bunkers full and all stores and equipment on board, ready for sea, she attained a mean speed of 18·55 knots. The total weight on this trial was about 70 tons.

The system of rudder adopted, with its partial balance, lends itself very readily to the use of rudders of large area. In addition to the advantage in rapidity of turning which increased area gives, there is a further advantage in twin screw ships, that a very small angle of helm is necessary in order to keep the vessel on her course with one screw only running. One degree of helm in this vessel was sufficient, and with one engine going full speed, the other screw dragging through the water, the vessel attained a speed of 17 knots per hour. With two engines and one boiler she attained 17½ knots. A further advantage in the system of rudder is the control it gives when going astern. The strain on the steering gear is somewhat greater, but the control is quite as complete as when going ahead. At full speed astern the speed attained on the

measured mile was 16 knots per hour. The circle turned going astern was smaller than when going ahead, but the time was longer.

Both these vessels were lighted throughout with incandescent electric light, and had a search light of 12,000 candles.

The *Destructor* was built for the Spanish Government, and is a vessel 192 feet long on water line, 25 feet beam, and 12 feet moulded depth. Her displacement fully equipped for sea, but with coal sufficient to steam 2,050 knots, is nearly 400 tons. The other leading particulars are given at the end of the paper.

The conditions to be fulfilled in this vessel were similar in character to the *Wiborg*.

(1) The speed to be 22½ knots per hour upon two trials, each of which to be of 3 hours' duration.

(2) The load at the trial to be 43 tons of stores, outfit, and equipment, 37 tons of coal, and 8 tons of fresh water for boiler service ; a load of 88 tons in all.

(3) Consumption trial of 12 hours, to show that 37 tons will drive vessel at least 1,500 knots.

(4) The armament to consist of one 9 cm. gun ; four 6-pounder rapid firing, two 47 mm. revolver Hotchkiss ; five torpedo tubes, two in the bow, one in the stern, and one in each broadside, each 15 feet long.

(5) Metacentric height not less than 3 feet.

(6) Pumping power to be 2,000 tons per hour.

(7) Bunker capacity to be sufficient for radius of action of 3,500 knots.

The considerations which led to the fixing of the dimensions of this vessel were very similar to those of the *Wiborg*, and the measures taken to give effect to these considerations were very similar. But as the chief object in making this vessel larger was to increase her habitability at sea, it was thought desirable to make her more like a small cruiser than a large torpedo boat. Bulwarks and a wood deck were fitted to her. The officers have five cabins and a ward-room. The engineers, stokers, and crew have separate quarters for each class.

The scantlings of this vessel are sufficient to give her a strength of 5·2 tons per square inch, assuming her to be balanced instantaneously on a wave of her own length and 11 ft. high. In still water her strains are practically nil.

The material of which she is made has a tensile strength of from 32 to 36 tons per square inch.

The vessel is divided into thirty-nine water-tight compartments. The engines in this case are in two separate engine-rooms, and the boilers are in four separate

compartments. Coal protection is afforded round the machinery and the boilers by the bunkers; but in addition, abreast of the engines, the bunker bulkheads are formed of steel plates ¾ in. thick, which are placed there to protect the machinery from machine-gun fire. Forward of the boilers and magazines is placed a curved bulkhead 1¼ in. thick to give protection from raking fire. The general arrangement of the vessel may be seen from Plates XVIII., XIX.

This vessel at her trials on the Clyde attained a mean speed of 22·56 knots for three consecutive hours. The mean I.H.P. developed was 3,784, and the mean revolutions of the two engines 292·0. On a subsequent three hours' trial the mean speed was 22·68, the I.H.P. and revolutions corresponding being 3,829 and 292·3. At the consumption trial the vessel was run at a mean speed of 11·6 knots for eleven hours on a total consumption of 57 cwt. This was obtained by using only two boilers, and the result corresponds to a radius of action of 4,929 knots at 11·6 knots. The mean I.H.P. over the eleven hours was 297, so that the consumption corresponds to 1·95 lbs. per I.H.P. per hour. The consumption of coal at the full speed trials, which were made with a mean air pressure of 2¼ in., was 2·4 lbs. per I.H.P. per hour. There is no doubt that a much lower rate of consumption per I.H.P. per hour was obtained between these two speeds, but no means were taken to measure it.

The consumption at full speed is not as high as might have been anticipated, and it gives the vessel an estimated steaming power of 540 miles at 20 knots. As a matter of fact she ran on January 24 and 25 from Falmouth to Muros (just beyond Finisterre), in twenty-four hours, a distance of 495 knots, which is at a mean speed of 20·625 knots. As the result of an application to the Meteorological Office for a report of the weather during this run the following has been received:—

"Wind was at daybreak at Falmouth S.S.E. moderate (force 4 by Beaufort Scale); subsequently freshened from about same point.

"Strong to fresh S.E. and S.S.E. breezes (force about 6) felt all across the Bay of Biscay. Sea most probably rather rough, but as the wind was blowing off the land the value given from our stations hardly represent the condition out at sea."

Captain Villaamil, the commander of the ship, reports that "the sea was rough, and vessel rolled and pitched considerably in consequence, but one could not wish to be in a better little sea-boat." I hope the members of this Institution will forgive my taking up their time with these details, but as no run of such great length, at such a speed, has to my knowledge been made before, I have thought it desirable to give the information in connection with it as completely as I am able. The vessel left Falmouth with her bunkers full, but I have no exact information as to the amount of coal burnt on the run above described.

As to the sea-going qualities of the *Wiborg*, she is reported to have behaved very well in her passage from the Clyde. On a part of her journey she went through a gale of wind, and I have received the following report from the Meteorological Office as to the weather at the time and place :—" Ship left Holyhead on morning November 5, 1886. Wind very light and variable, sea smooth. Afternoon, wind drew into N.W., light to moderate till night, and sea slight. During the night of the 5th and early morning of 6th wind rose to a fresh gale (force 8), from W.N.W.; sea very rough; wind and sea both decreased a little after passing Land's End."

She steamed at 10 knots, so that the above is only a guide for cruising purposes. The metacentric height of the *Wiborg* varies from 2·5 light to 2·3 loaded, and the *Destructor* from 4·9 light to 4·3 loaded.

As may be seen by reference to the particulars at the end of the paper, the *Wiborg* has compound engines, working at 130 lbs. boiler pressure. The *Destructor* has triple expansion engines, working at 145 lbs. From an estimate of the weight of steam used per I.H.P. per hour in these two cases, taken from a considerable number of diagrams, it appears that in the compound the consumption is 19·0 lbs., and in the triple it is 15·33 lbs., or a saving of 19·3 per cent. in favour of the latter, neglecting any advantage due to the small difference of pressure.

The rudders of these two vessels are a departure from ordinary practice. That of the *Wiborg* is flat, and of about 40 square feet in area. In the *Destructor* an extension of this system is adopted, and it is combined with an under-water rudder head. The rudder is formed as a continuation of the after-body lines down as far as the bottom pintle. The dead-wood is arched up to allow the forward compensating part to work freely. By making the rudder of the form shown, the length of the ship is virtually increased while the resistance to turning remains the same. By an extension of this system it is possible to obtain the advantage of the long ship with its consequent extra speed, and the rapidity of turning of the short ship, both of which advantages are of the first importance to a war-ship.

Plates XVII. and XIX. show the *Wiborg* and *Destructor* with some of the principal compartments flooded.

I have collected these facts in order to place on record in this Institution a description of two small vessels, which are each in some respects unlike anything of the kind which had been done before.

The following are the leading particulars of these two vessels :—

	Wiborg.	Destructor.
Length between perpendiculars...	142 ft. 6 in.	192 ft. 6 in.
Breadth	17 ft.	25 ft.
Depth at centre	9 ft. 6 in.	13 ft.
Normal displacement	133 tons.	385 tons.
Load displacement	167 ,,	458 ,,
Draught due to normal displacement	4 ft. 7 in.	6 ft. 3 in.
Draught due to load displacement	5 ft. 2 in.	7 ft. 0 in.
I.H.P.	1,400	3,800
Revolutions	380	292
Diameter of cylinders	14 in. and 24½ in.	18½ in., 27 in., and 42 in.
Stroke of cylinder	15 in.	21 in.
Number of boilers	2	4
Pressure...	130	145
Grate surface	56	144
Number of torpedo tubes	2 in bow 1 on deck	2 in bow 1 in stern 2 on deck
Number of torpedoes	6, 19 ft.	6, 15 ft.
Number of guns carried...	2, 37 mm. Hotchkiss Revolvers.	7 1, 4 in. B.L. gun 4, 6-pounders 2, 47 mm. Hotchkiss Revolvers.
Number of officers and crew	22	45
Normal coal	14 tons	37 tons
Radius of action due to ditto, at 10 knots ...	1,400 knots	2,050 knots
Total bunker capacity	45 tons	110 tons
Radius of action due to ditto, at 10 knots ...	4,000 knots	5,500 knots

	Wiborg.			Destructor.		
	1st trial.	2nd trial.	Deep trial.	1st trial.	2nd trial.	Deep trial.
Load carried on speed trial	41	34	70	88	88	161
Displacement at trial	138	131	167	385	385	458
Mean speed for three hours	19·96	20·6	18·55	22·56	22·68	20·2
Revolutions, mean speed for three hours	381	380·1	362	292	292·3	
I.H.P.	1,303	1,405	130	3,784	3,829	

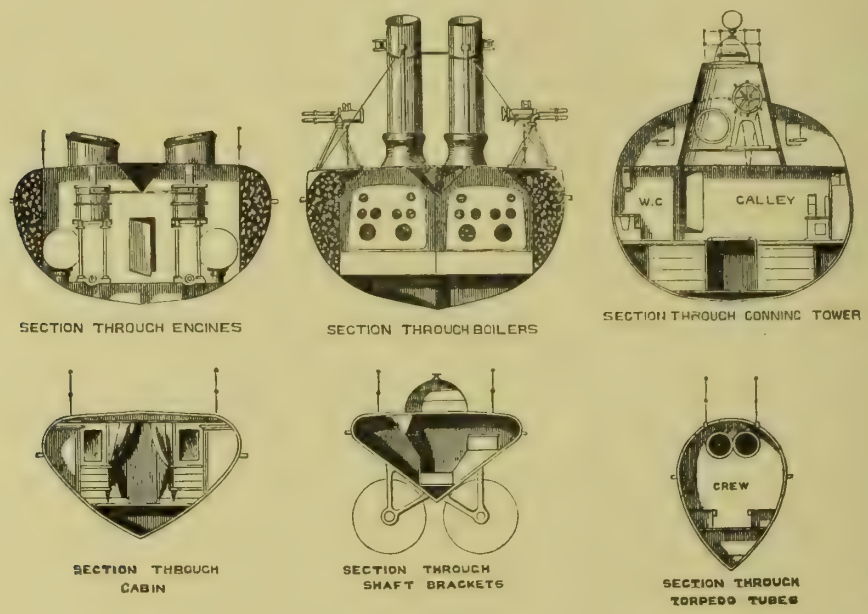
	Wiborg.
Speed astern	16 knots.
Revolutions at full speed astern	332
Time from signalling full speed astern till vessel was at rest...	0′ 30″
Time from ditto till vessel was at position at which signal was made	1′ 11¾″
Distance traversed	146 yards each way.

Time required to put helm over hard ...	8½ secs.	11 secs.	8½ secs.	12 secs.	8 secs.	8 secs.
Time to complete circle...	1′ 37″	1′ 34″	1′ 28″	1′ 28″	2′ 47″	1′ 59″
Diameter of circle	160	175	220	230	150	150
Speed before going on circle	15	14·3	16·4	16·6	8·0	11·6
Speed on circle	10·7	11·2	14·2	14·6	5·03	7·0
Ahead or astern	Ahead.	Ahead.	Ahead.	Ahead.	Astern.	Astern.

The diameters recorded when going astern seem to indicate that the diameter is not reduced by a diminution in the speed to anything like the same extent as when going ahead.

At a speed of 21·7 knots the time to complete the circle was 1 min. 13 secs., but the diameter was not observed.

WIBORG.



DISCUSSION.

Admiral A. F. R. DE HORSEY (Associate): My Lord, I hope some qualified gentleman present will tell us what we are doing in this respect. I have not got up to make a speech, but merely to say this: that I do not believe there is *another vessel in the world* that can go from Falmouth to Muros in twenty-four hours. I shall look with some anxiety to distinguished gentlemen connected with the Admiralty who are present, to know if they can tell us whether we can do the same.

The PRESIDENT: There is a challenge thrown out, gentlemen; will anybody take the glove up?

Mr. J. I. THORNYCROFT (Member of Council): My Lord, I had not intended to make any remarks upon these vessels, but there are some points in them which are of interest. There is one point which forcibly illustrates what Mr. West said this morning, viz., that in vessels like torpedo-boats, which generally have a very large amount of spare buoyancy, you can flood a considerable part without sinking them, or causing much danger. The rudder of these vessels has the advantage of being very simple, and it does its work well. The deadwood being cut away, the water, which is impelled sideways relatively to

the vessel, is allowed to continue its course, and in going astern I believe the steering is quite satisfactory. It seems, however, to me, to be open to the objection that it is very liable to catch in such a thing as a cable, or anything which otherwise the vessel might pass over. The advantage of the rudder forming part of the lines of the boat is questioned by some, but I think it must be an advantage, although my friend Mr. White would say it does not make any material difference. The division of the engine-room into so many compartments is no doubt a good feature where a boat of this class is so likely to be perforated. In small craft we must really look to taking the bullets through harmlessly rather than stopping them. The armour which is put upon this class of vessel must materially reduce the speed, and is more a disadvantage than of value, because it really won't stop the shot of quick-firing guns. I think the vessel which is somewhat protected, would have been a more valuable vessel had that protection been dispensed with. I do not know that there is anything further that I wish to say upon this subject. I hope some other gentleman will take it up.

Mr. S. W. Barnaby (Member): There are one or two points which I should like to ask Mr. Biles to give us some further information upon. The drawings are on rather too small a scale to show what I wanted to know. First of all, I would ask him whether the water-line shown on this drawing with the torpedo compartment filled, is the result of experiment or calculation?

Mr. Biles: Calculation.

Mr. Barnaby: Then I also want to know whether there are any doors in those bulkheads enclosing the bilged compartment; and if there are doors, whether he thinks they would be reasonably tight. The next point is, that I observe in the *Destructor* there is no communication apparently below deck between the engine-room and the forward boiler-room, and I cannot see how this could very well have been avoided. It is a common criticism in connection with torpedo-boats with more than one or two boilers, that you cannot work boilers properly which are not under the immediate supervision of the engineer in the engine-room. I do not think myself this is a very difficult point, but I believe this is the first torpedo boat which has been worked under these conditions, and I would like to have the result of Mr. Biles's experience upon it. That is all I have to say.

Mr. W. H. White (Vice-President): My Lord, I am very much afraid that the meeting hears me too frequently, but after the question which has been put by Admiral De Horsey, I think somebody should say what is being done by the Admiralty in the same direction. The Admiralty have not at the present time any vessel of this size with the same speed as the *Destructor*. The corresponding vessel in the English service belongs to what is known as the *Rattlesnake* class of torpedo gunboats, and the speed attained by the first of those vessels in her trials on the measured mile is 19½ knots, the designed speed having been 19 knots. Those are the facts. As to how this difference of speed comes about, and as to why the Navy has not vessels as fast as the *Destructor*, it is not for me to say anything, and I do not propose to say anything. There are certain points in the paper itself to which, as I have risen, I should like to refer. I have had the advantage of seeing the two boats, and I may say that they both represent good pieces of work both in design and execution. There are certain experimental features in these vessels which must strike the eye of anyone familiar with construction of this nature, and it would be interesting to note how far in subsequent experience the considerable departure from previous practice which has been made in the scantlings of the larger vessel will be justified by results. I need not say that the limit of scantlings in the smaller classes of vessels is fixed by other considerations than what may be classed as "general structural strength." In designing

floating structures like ships it is not possible to make proportionate reductions in scantlings as size is reduced. Starting from a large ship, the scantlings which should, by the rules of proportion, suffice in a ship of much smaller size, would lead to a degree of limits of "thinness"—I was going to say, limits of "thickness"—which would be inadmissible because of other considerations. Now in these vessels the great principle has been adopted that the limiting considerations are not those of general structural strength, and the scantlings, which have proved quite sufficient so far as I know up to the present time for all these severe speed trials and for limited service at sea, are undoubtedly lighter than have been previously used in vessels of the same size. It is certainly to the credit of Messrs. Thompson that they have dared to make this experiment, and that so far it has proved successful. They have thus added to our knowledge of how slightly we can construct some classes of sea-going vessels, and when experience has been gained of these vessels as to their behaviour, their durability, and power of keeping the sea, we shall have learned a lesson which I have no doubt will be profited by, by other designers and builders. Another point which I think is of great interest here is, that in the *Wiborg* twin screws have been applied to a vessel which is distinctly a torpedo boat. I almost hesitate to allude to twin screws in this Institution, because I am supposed to be a fanatic on that subject. But I remember perfectly well, a good many years ago, when a number of first-class torpedo boats were being built in the Navy, I strongly advocated the adoption of twin screws, with the conviction that there would be no loss of efficiency in any respect, while there would certainly be gain in many ways. It is a great comfort to find, when one has advocated an opinion which is to some extent speculative, that the opinion is justified by results. That is not always true, but in this case it is true. There have been in the past year trials of two vessels, fortunately almost simultaneous trials, which enabled an excellent comparison to be made. Mr. John Samuel White, of Cowes, built a single screw vessel for the English Navy, which in the conditions of trial and dimensions is very fairly comparable with the *Wiborg*. She had a single screw, and had practically the same arrangement of the boiler-rooms—I mean as to the number of boilers—as the *Wiborg* had, with twin screws and separate engines. Now, as a matter of fact, the performances of the two boats were almost absolutely identical. I do not mean to say that the speeds were absolutely identical, or that the displacements on trial were absolutely identical, but making allowance for what really happened at the trial, the performances tested by the ordinary rules of efficiency were practically the same. That is to say, the single screw had not the advantage over the double screw which the experienced builders of these vessels thought the single screw would have. Since that a trial has been made of another twin-screw boat, which, so far as I have been able to judge, shows that not merely is the balance of efficiency equal, but that if anything, as regards higher speeds on limited draught, the twin screws have the advantage. When Mr. Thornycroft tries his Spanish boat, which I believe he is intending to do shortly with twin screws, he will be able to say whether or not that general view is correct. It is greatly to the advantage of everybody who is engaged in designing and building ships, that, instead of the old exclusive idea of keeping facts entirely to themselves, we shall have firms who will have the generosity to this Institution that Messrs. Thompson have shown to-day.

Mr. F. C. Marshall (Member of Council): My Lord, we are very much indebted to Mr. Biles for having laid before us the valuable information contained in his paper, and also the result of the experimental working of the *Wiborg* and the *Destructor*. I think it would be very much in accordance with the necessities and objects of this Institution if Mr. Biles would give us in his reply some account of the working of the vessels under these high speeds. I have reason to believe that they suffered very much in some of the trials from excessive vibration, and it will be very interesting if Mr. Biles will tell us how they get rid of that vibration in vessels going at this speed. I am the more

interested in this matter, my Lord, personally, as I happen to be suffering seriously from that infliction myself. It has fallen to my lot not only to fit vessels of this class—this *Destructor* class—though of rather larger capacity, not only with twin screws, but with three screws. The trials of these vessels are not yet completed, but so far as we have gone they tend to show, that not only may we derive full advantage from two propellers, but—and I speak with all respect to Mons. de Bussy, who holds the view of the other side—we can have equally full efficiency from three propellers when they are properly disposed. I speak now of the trials of the Italian torpedo cruiser *Tripoli*, and these, my Lord, I hope to have the honour of laying before this Institution at our meeting in Newcastle, and so following up and forming a supplement to this very interesting paper. At the same time I hope to be able to further confirm the views expressed by Mr. White with reference to the efficiency of twin screws in the torpedo chasers now being built for the Russian Government, and the trials of which I hope to have completed in the course of another two or three months. But I would specially ask Mr. Biles to be as full and explicit in his explanation of the vibrations of the vessel, and of how they were overcome, as he can be. It would be of very great interest to the Institution if they knew that, and if they had a clear expression of his experience in the matter. My Lord, I can only express what Mr. White has already said, that the information we are receiving to-day in regard to this class of vessel is of the most valuable character, and is only equalled by that which was contributed by our friend Mr. Thornycroft on the torpedo boat, and which constituted what I may denominate as an entirely new departure.

Mr. H. F. Swan (Member): I should just like to ask Mr. Biles a question with regard to the water-tight bulkheads. I believe these vessels are of very light construction; and, moreover, that their seaworthiness in case of being damaged is entirely dependent, or, if not entirely dependent, in a large degree dependent, on the bulkheads standing. Now, it occurs to me, looking more particularly to the central bulkhead, that in case the vessel were pierced in the manner indicated, the loose water on one side of the bulkhead would be very apt to start it, unless it was very efficiently stayed. I should like to ask Mr. Biles whether these bulkheads have been tested in actual practice with a head of water considerably higher than the deck, which would probably be the only way that a builder would have of proving the strength of the bulkheads.

Mr. J. H. Biles (Member): My Lord and Gentlemen, I have to thank you in the first place for the way in which you have received this paper, and in reply to the remarks of Mr. Swan and Mr. Barnaby about the bulkheads, I may say that each of those compartments has been tested by being filled, the bulkhead doors being shut, so that the test has been more severe than anything that is shown in these diagrams. How long these doors will remain water-tight depends upon the care that is bestowed upon them in looking after them. All I can say positively is that they were perfectly water-tight. The stiffening that was put in was ample for the work that was intended. With respect to fouling the rudder, that is naturally an objection that occurs to one in looking at a diagram of that kind. But there is one thing that is apt to be forgotten. These vessels are both twin-screw vessels, and the screws are abreast of the rudder, or nearly. You cannot help having your propeller there. If a rope or a hawser gets itself across there, it is sure to foul the propeller rather than to foul the rudder, and in that way, as you have an unavoidable projection there, I think the objection of having a rudder which may possibly be liable to be fouled is very much reduced in value. With respect to the question of having armour protection abreast of the machinery, there is no doubt that what Mr. Thornycroft said was true, and that you can penetrate these bulkheads if you hit them square on, but there would also be likely to be coal abreast of them, because the coal in the space abreast of the engines would be left to the last, and with that coal and with the $\frac{3}{4}$ in. of armoured protection, I think you

would stand a very good chance of keeping those shots out when they strike at any angle except square on. With respect to Mr. Barnaby's remark about not having a passage through, I think the diagram is clear on that point. There are doors in this vessel, and there are passages through alongside the boilers, arranged so that you can pass from the stem to the stern of the vessel underneath the deck. That feature was introduced in the design, and, in my opinion, is a necessity in such a ship. You can pass from right aft of the steering-gear space through the crew's compartment, aft through the engine-room, through the boiler-rooms, up into the steering-engine space, and right forward, being the whole time underneath the deck. I think that answers Mr. Barnaby's question. With respect to Mr. White's remarks about the scantlings, he has with his usual clearness expressed the pith of the whole question. This vessel is a high-speed vessel, because her scantlings are light. Every precaution has been taken in the arrangement of the structure that the greatest possible strength should be developed with the scantlings. Almost everything in the hull contributes, I think, to the structural strength of the vessel, in addition to performing purposes of domestic and other non-structural uses. Every plate in the vessel has been galvanised, and the steel is of high tension, from 32 tons to 36 tons. There is no doubt that the vessel, in order to be of use at any time, must be carefully preserved, and this is a thing that *can* be done. If the vessel is well looked after she is always capable of producing the speed that she has already done. With respect to the question of vibration, I should have said something in the paper if I had had anything definite and quantitative to say about it. It is a little difficult to speak offhand clearly as to the experience of the trials we had in this vessel, but I may say in the first place that we had a long series of trials with different propellers. The engines were designed to run at 350 revolutions, but we knew that the power could be got at 300. We hope to get a good deal more power than we did, but in trying the vessels with the first set of propellers on we found that when we exceeded a certain number of revolutions, which was about 310, the vibrations of the hull became excessive. This was also shown by the fact that when the engines were running at about half that number of revolutions the vibrations then were marked, but not excessive. The problem then became one of obtaining the power from the engines with a propeller which would give the speed with revolutions not exceeding about 300. Considerable difficulty was experienced in exactly hitting the conditions. One set of propellers that we made would give too few revolutions and not enough power; another set, which we thought would give not too many revolutions, gave too many, and caused these excessive vibrations. But I think the problem we have to solve in vessels of light scantling is to find out what is the period of vibration, and then to so time the speed of the engine that it shall not synchronise with this period of vibration. If it does, then excessive vibration is sure to set in. If you keep clear of that point you keep clear of excessive vibration, and as long as you do not have excessive vibration I see no reason why vessels of light scantling like this should not hold together as long as vessels of heavier scantling. I have again to thank the meeting, my Lord, for the attention with which I have been listened to.

The President: Gentlemen, I am sure you would wish me to return our united thanks to Mr. Biles for his valuable paper, and I may also congratulate you upon the interesting discussion which has ensued upon it. There is one expression which fell from my friend Mr. White which I should wish particularly to emphasize, namely, that in which he recognised the candour and fulness with which Mr. Biles has expressed the result of his experience in these trials. The very essence, Gentlemen, of the valuable discussions which take place here are the fair and clear interchange of views and the results of experiments conducted by persons competent to understand and conduct those experiments. That forms the very essence of our discussions, and that really, I believe, constitutes their immense value in the eyes of all students, either of naval architecture or marine engineering. Therefore,

whether that interchange of views is with our foreign members or with our competitors as home, they are of equal value, and will, I am sure, always be held by this Institution at their just value. I am sure you will allow me to return our thanks to Mr. Biles for this paper.

Mr. Biles: I want just to remove any chance of misapprehension by saying that the propeller which was finally fixed upon for this vessel enabled her to be driven at the speed at which she was driven with practically no vibration. That was the final result of our trials.

FIFTY YEARS OF YACHT BUILDING.

By Dixon Kemp, Esq., Associate Member of Council.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

It can fairly be said that yachts, such as we are now accustomed to, have been entirely developed during Queen Victoria's reign. Fifty years ago there were probably not one hundred yachts in existence above 20 tons, and these were modelled after the brigs, schooners, or cutters of the Royal Navy. Their scantlings were somewhat lighter, and their ballasting perhaps not quite so good, as in some cases weight was made up with stone. The brigs were about the size of those of the Royal Navy, and were considered superior to them in sailing qualities. One of the best known of these brigs was the *Waterwitch*, built by Mr. Joseph White, of Cowes, in 1832, for the Earl of Belfast (afterwards Marquis of Donegal). This brig had a great reputation for speed and weatherliness, and beat H.M.S. brig *Pantaloon* about four miles in a six hours' sail to windward. This achievement led to the *Waterwitch* being purchased by the Admiralty, and subsequently to the employment of Mr. White to build other brigs for the Royal Navy, notably the *Daring*. This vessel and the *Waterwitch* performed the best to windward in a strong wind and head sea in the experimental sailing of 1844.*

Although brigs and schooners were occasionally sailed in competition, it was found that the cutter rig was so vastly superior in point of weatherliness, that its adoption for almost all yachts intended for racing was a matter of natural selection. At first—that is, between the years 1815 and 1837—there was seldom any time allowed for difference of size, and the result was that with anything like a breeze the largest vessel came in first and won. As there was no tax of any kind on any of the dimensions there was no inducement on that score to alter the proportions of length, breadth, and depth from the prevailing Admiralty type. These proportions were from 3 to 3½ beams to length of water-line, and the greatest transverse section was placed ahead of the middle of length, varying in distance from one-tenth to one-fiftieth of the length. The centre of buoyancy was generally situated at about the centre of length, and it appears to have been an aim of the designers to keep the displacement of the fore-body and after-body

* *Vide* Parliamentary Paper, No. 394 (B), 1845.

equal. The upper horizontal water-lines of the bow were short and full, making an angle of about 30° with the centre fore and aft line; and the load water-line aft was generally a trifle fuller, but the buttock or vertical lines were long and flat. This kind of yacht is familiar to us as the cod's head and mackerel's tail type, and was firmly believed in even by men who took some trouble to investigate the qualities of hull which led to success in sailing. Such was the late Mr. Fincham, master shipwright of H.M. Dockyard, Portsmouth, who designed several yachts for members of the Royal Yacht Squadron, Cowes. One of these was the *Fair Rosamond* schooner, built in 1846 by Mr. Camper, of Gosport, for the late Duke of Marlborough. Mr. Fincham, in his papers on Naval Architecture and Yachts, states that the centre of buoyancy of the *Fair Rosamond* was ·004 in terms of the length abaft the middle of length; she won some prizes at Cowes, but Mr. Fincham concluded that she would have performed better in a head sea had her centre of buoyancy been farther forward. Accordingly in the following year—1847—he designed the *Novice* schooner for the Earl of Desart, and placed her centre of buoyancy ·01 ahead of the middle of length, or, in other words, nine inches farther forward than the other's was. Mr. Fincham declared this to have had a great effect on the performance of the vessel, but, judged by the light of subsequent events, there is no doubt that Mr. Fincham was much mistaken in attributing so much subtle influence to slight variations in the fore and aft positions of the centre of buoyancy.

About this time the theory of the late Mr. John Scott Russell (that the bow should be longer than the stern) began to be accepted as nearer the truth than the old theory of the cod's head; and in the year 1847, whilst Mr. Fincham was designing the *Novice*, a very remarkable vessel was built on the Thames as an exponent of Mr. Scott Russell's theory. This was the *Mosquito* cutter (Plate xx.), of 59 ft. water-line and 15 ft. 4 in. beam, built by Mr. Mare,* of Blackwall, and launched in 1848. The *Mosquito* was like one of the cutters of the period turned end for end; her bow was long, and made an angle of only 17° with the centre fore and aft line, and had besides 2½ in. hollow. Her after-body was short, showing great fulness both in the horizontal and buttock lines. Her midship section was placed 4 ft. 6 in. abaft the middle of length of water-line, and her centre of buoyancy was 2 ft. abaft it.

According to the old practice, the *Mosquito* should have had no good qualities at all, especially in strong winds; but the fact is, she excelled in all the good qualities claimed for the bluff-bowed craft; she was faster than any other yacht of her length, on any point of sailing, and in a strong wind to windward was a marvel compared with other yachts. However, so strong was the prejudice against the "long, lean bow," and

* There is some doubt as to whether Mr. Ditchburn or Mr. Waterman or Mr. Mare designed the *Mosquito*, but Lord Brassey, in an article in *The Fortnightly Review*, 1883, says: "Mr. Mare was the author of her existence both in idea and in fact." It should be said that Lord Brassey at the time she was building had special means of knowing.

so alarming the predictions—that some day the *Mosquito* would take a dive and never come up again—that no one could be found to try the experiment on a more extensive scale. It thus seemed likely that the old type would be continued in spite of the *Mosquito* having, in a superior degree, all the good qualities it was contended a yacht should have.

It will be here convenient to take a glance at what was being done on the other side of the Atlantic at this time. It should be said that the Americans had not as yet settled down to any kind of sport so as to give it a nationality, and had consequently evolved no special type of yacht. So far as can be learned, the first American yacht race took place just fifty years ago, and it does not appear that any yachts existed in the States before 1835, and those built subsequently, up to the year 1844, were small schooners. In the year named, however, a remarkable vessel was built at Hoboken named *Maria*, on the lines of the flat-bottomed coasters. She was 100 ft. on the water-line, with an extreme beam of 26 ft. 8 in., and draught aft of 5 ft. 3 in. She was fitted with a centre-board which dropped 16 ft. below the keel, and also had a small one aft to prevent her griping. She had a long hollow bow, and was sloop rigged, with jib and mainsail only. The foot of her mainsail was 92 ft. long and the foot of her foresail or jib 70 ft. This vessel may be said to have been the original of the American centre-board yacht; but although she showed extraordinary speed and weatherliness there appears to have been a conviction that more depth of body and less beam would be better for good sea-going qualities. At any rate George Steers (the son of a Devonshire shipwright who had settled in New York) produced the keel yacht *America*, which was destined to have such an important influence on British yacht building and sail-making. In the *America* (Plate xx.) the principles so successfully carried out in the *Mosquito* were embodied with equal success; her bow was long, making an angle of 16° 30′ with the centre fore and aft line, and showed besides 7 in. hollow. She had a short run, and the centre of buoyancy was considerably aft of the middle of length, as will be gathered from the accompanying table:—

	Mosquito.	America.
	Feet.	Feet.
Length on water-line	59·2	87·3
Breadth, extreme	15·3	23·8
Draught of water, extreme	11	11·5
Proportion of beam to length	0·257	0·272
Midship section aft centre of length in terms of length of L.W.L.	0·076	0·071
Centre of buoyancy ditto	0·032	0·041

The *America* visited us in 1851, and achieved a remarkable success at Cowes over our schooners. This success was no doubt mainly due to the qualities of her hull, but the unusual flatness of her sails contributed greatly to her fine weatherly qualities. The immediate effect of the *America's* success was rather startling; almost every yacht in existence at that time, including the *Fair Rosamond*, was lengthened by the bow, her masts raked, and sails laced to the booms; and the principles which had been so strikingly exemplified in the *Mosquito* three years before, were now adopted as a new discovery of infallible merit. This marked the commencement of a new era in yacht designing, and the subsequent development of yachts into the now fashionable narrow type, has shown no considerable departure from the principles observed in the design of the *Mosquito*, so far as relative length of bow and stern goes.

There have, however, been causes at work which have largely influenced the proportions of yachts. Allusion has already been made to the fact that fifty years ago there was no such compensating reckoning to deal with as time allowances for differences of size. As soon, however, as yacht racing became a general summer pastime, a rating for size became a necessity, and the size test adopted was simply the registered tonnage of the day, or what we now know as builders' measurement.* This measurement took no account of depth, but assumed that it always equalled half the breadth. Frequent competition, and the teachings of investigators of naval science, impressed yacht builders very forcibly with the fact that the element of size which gives speed is length; and that if two yachts were of equal tons, but one should happen to be longer than the other, then the longer boat would be certain to prove the faster, all other things being equal, such as sail spread, stiffness, fairness of lines, &c. Or if two vessels were of equal length and one measured fewer tons than the other, then her rating would be smaller, and she would receive a compensating time allowance.

For a great many years the obvious tendency of the tonnage rule to produce relatively long and narrow boats had little effect, because breadth was so essential to enable a vessel to carry a large sail spread. Naval architects were, it is true, alive to the fact that stiffness could be gained by depth of hull, suitably ballasted, and Mr. T. Wanhill, of Poole, was the first to recognise this and make use of depth; but this untaxed quantity could not be made use of to any great extent, on account of the heavy displacement it involved; consequently, down to the year 1870, the racing yacht developed very slowly, and at that time a length of $4\frac{3}{4}$ beams for cutters and 5 beams for schooners was considered sufficiently extreme. From the date named, however, length for any given tonnage showed a very rapid increase, whilst breadth necessarily decreased. Lead keels, it should be said, had some years previously—about the year 1846—been introduced as a means of increasing stiffness after shifting ballast to windward during

* This measurement is $\frac{(L - \frac{3}{5} B) \times B \times \frac{1}{2} B}{94}$.

match sailing had been abolished; but lead keels were regarded with a great deal of disfavour by yacht-owners, from the prevailing belief that they made a vessel pitch and roll heavily in a sea; thus up to 1870 no yacht was to be found with more than about a tenth of her ballast on the keel, and the majority had none at all. Some experiments, however, with small vessels, and a better knowledge of the good effect of concentrating the ballast in the middle third of the length of the vessel, rapidly led to a larger quantity of lead being placed outside, until, at last, the whole ballast was placed outside on the keel.* This lowering of the ballast, and consequently of the centre of gravity, enabled the designer to dispense with a considerable quantity of breadth and add to the length, for any given tonnage, until in some of the smaller yachts the length has been equal to 6½ beams, and in the larger, 5¾ beams.

For any given nominal tons the displacement has been largely added to, as may be gathered from the table on next page; but this, whilst perhaps it has checked the attainment of the highest possible speed for any given length of hull and sail spread, has prevented the yachts being useless as seaboats.

These large additions to the displacement, whilst the power for getting through a head sea may have been increased, have had a prejudicial effect on the attainment of high speeds, mainly on account of the enormous wave-making it induced. Thus, so recently as 1880 the *Arrow* (Plate xx.) has been driven in strong winds as fast and sometimes faster than the *Formosa* or *Samœna*, and with very considerably less wave disturbance. The principal characteristic of this wave-making is a huge hollow under the weather bilge, although there is a considerable hollow on the lee side as well. The fact, however, that the greatest disturbance is found on the weather side is accounted for by the circumstance that, upon heeling over, the bulk of the deep displacement is on the weather side of the middle fore and aft line. The lead keel of one of these long narrow yachts, it should be explained, is in breadth about one-third of the main breadth of the vessel; and in weight is equal to about 0·5 of the total weight of vessel in a yacht like the *Galatea* (Plate xx.), to 0·7 of the total weight in a 3-tonner.

The Americans, it should be observed, did not much alter this centre-board type of yacht and keel yacht during the period between 1845 and 1885. The reason of this was mainly due to the fact that they frequently changed their method of rating for competitive sailing, and, moreover, did not pursue yacht racing to the extent we did on this side of the Atlantic. Their yachts for any given length were capable of a greater absolute speed than our yachts in moderate breezes and pretty smooth water, because they were of much lighter displacement; in very light winds the British type seemed to have the advantage when the sail spread to immersed surface was about the same in each yacht; in strong breezes the shallow American type had the advantage in speed

* A paper on this subject will be found in the Transactions of the Institution for 1880.

	Arrow.*	Formosa.	Vanduara.	Samœna.	Genesta.	Galatea.
When built... ...	1822	1878	1880	1880	1884	1885
Length on load-line..	76 ft. 7 in.	82 ft.	81 ft. 3 in.	80 ft. 8 in.	81 ft.	86 ft. 9 in.
Breadth, extreme ...	18 ft. 9 in.	16 ft. 11½ in.	16 ft. 2 in.	16 ft. 2 in.	15 ft.	15 ft.
Draught, aft ...	11 ft. 6 in.	12 ft. 6 in.	12 ft. 4 in.	13 ft.	13 ft.	13 ft. 6 in.
Yacht tons	99	83	89	88	80	90
Displacement in tons	106 tons.	130 tons.	130 tons.	129·8 tons.	141 tons.	157·7 tons.
Area of midship section	89 sq. ft.	100 sq. ft.	—	—	—	114 sq. ft.
Midship section abaft middle of length of L.W.L. ...	5 ft. 5 in.	4 ft. 6 in.	3·75 ft.	5·5 ft.	4 ft.	4·2 ft.
Centre of buoyancy abaft middle of length of L.W.L.	3 2 ft.	2 ft.	1·98 ft.	3·52 ft.	—	2·1 ft.
Area of immersed surface	1,940 sq. ft.	—	1,892 sq. ft.	2,022 sq. ft.	—	—
Ballast	40 tons.	60 tons.	—	—	72 tons.	81·5 tons.
Portion of this ballast on keel and in garboards ...	13·7 tons.	14 tons.	—	—	70 tons.	81·5 tons.
Area of mainsail ...	3,000 sq. ft.	3,150 sq. ft.	—	—	—	—
Area of foresail ...	700 sq. ft.	750 sq. ft.	—	—	—	—
Area of jib	980 sq. ft.	990 sq. ft.	—	—	—	—
Total area lower sail.	4,680 sq. ft.	4,890 sq. ft.	4,500 sq. ft.	4,575 sq. ft.	—	—
Mast, deck to hounds	49 ft. 4 in.	48 ft. 8 in.	48 ft. 6 in.	50 ft.	52 ft.	53 ft.
Main boom	64 ft.	68 ft.	68 ft. 3 in.	68 ft.	70 ft.	73 ft.
Main gaff	46 ft.	44 ft. 8 in.	43 ft. 3 in.	44 ft.	46 ft.	45 ft.
Bowsprit outside ...	34 ft.	34 ft.	31 ft.	34 ft. 3 in.	35 ft.	36 ft. 6 in.

* Although the *Arrow* was built so far back as 1822, she has been many times altered, and originally her length on the water-line was 59 ft., and beam the same as it is now.

when sailing well off the wind, but when pressed close to the wind the advantage was just the other way. This appears to be principally owing to the fact that the narrow, deep yacht has practically an unlimited range of stability, whilst the shallower and broader yacht of the American type reaches the maximum of her range at an angle of about 30°. In a short head sea the heavy narrow yacht has an advantage over a lighter yacht of the same length.

The results of some encounters between small yachts of the United States and those of England during the years 1881, 1882, and 1883, at New York, Boston, and other places, led Americans to consider whether some adaptation of their centre-board type to the British type could not be carried out with advantage. It was made plain to them that a yacht of the British type would win a majority of races, but the type was already condemned in England, and Americans could not be persuaded to adopt it without modification. Accordingly, when in 1885 the owner of the British cutter *Genesta* challenged for the cup won by the *America* at Cowes, in 1851, the Americans set to work to produce a compromise yacht, but distinctly more American in type than British. This yacht in section was of the broad V character—very like the *America* of 1851—with almost twice the draught of water that the ordinary shallow centre-board yacht had. Beyond this she had nearly the whole of her ballast outside, in the form of a lead keel supplemented by a centre-board of considerable area. This yacht was named *Puritan*, and, so far as can be judged, she defeated the *Genesta* on her merits. The same fate befel the *Galatea* last year, the Americans having built another yacht, the *Mayflower*, of this new type to meet her. They compare as follows :—

	Galatea.	Mayflower.	Genesta.	Puritan.
Length on water-line ...	87·0 ft.	85·7 ft.	81 ft.	81 ft.
Extreme beam	15·0 ft.	23·5 ft.	15 ft.	23 ft.
Draught of water ...	13·50 ft.	9·0 ft.	13 ft.	8 ft. 3 in.
Area of transverse section	114 sq. ft.	85·0 sq. ft.	—	—
Displacement	157·63 tons	110·0 tons	141 tons	105 tons
Total ballast	81·50 ,,	48·0 ,,	72 ,,	44 ,,
Ballast on keel	81·5 ,,	42 ,,	70 ,,	27 ,,

The success of *Puritan* over *Genesta* and *Mayflower* over *Galatea* naturally produced a great impression on this side of the Atlantic, especially as the two American yachts were the work of one who at the time could only be regarded as an amateur at yacht designing. But there is no doubt that Mr. Edward Burgess had made a very

close study of both English and American yachts, and his success was as much the result of a correct appreciation of what was required to achieve a certain object as that of George Steers was when he designed and built the *America* in 1851.

The practical outcome of the victories of the American yachts was that the British Yacht Racing Association realised the situation that whilst its rating rule (which taxed beam heavily, and depth not at all) might produce yachts which were in some respects superior to the American type, yet that there are intermediate types of surpassing excellence so far as match-sailing is concerned. The old tonnage rating, it can be said, had assisted in bringing yacht building to a stand-still in this country, as no one could be found willing to build a longer, narrower, and deeper boat for any given tonnage than those which already existed, and the rule* would not admit of trying experiments with beam.

Under these circumstances the Yacht Racing Association appointed a committee to report upon the existing rating rule, and recommend such new rating as might be considered necessary. The committee obtained the opinions of all the leading yacht designers and yacht builders, and these were almost unanimous in recommending that the rating should be in future by length of load-line and sail area, the working formula being—

$$\text{Rating} = \frac{\text{Length} \times \text{sail area}}{6{,}000}.$$

The first outcome of this rule has been that the new Scotch yacht *Thistle* (built expressly to compete for the *America* cup) has been designed of proportions very similar to those of yachts of thirty years ago, before the squeezability of the old tonnage rule had been discovered. The actual dimensions of this yacht are :—

Length of load-line	85·00 feet.
Breadth, extreme	20·30 ,,
Depth of hold	14·10 ,,
Registered tons †	100·67 tons.

The *Thistle*, it should be said, has been designed by Mr. G. L. Watson, of Glasgow, and is the first attempt since the *Livonia* was built, in 1871, to meet the Americans on their own lines. She will probably have to encounter one of the powerful centre-board sloops, and it is contended, with some reason, that a contest between a keel yacht and one fitted with a centre-board cannot be considered a satisfactory trial of merit. So far as sailing by the wind is concerned, the board does not appear to hold the yacht to

* The rule had been modified from the old tonnage rule to $\frac{(L + B)^2 \times B}{1730}$.

† The apparent large registered tonnage of this yacht is attributable to the fact that she is built of steel, and that her keel is specially constructed to form a kind of ballast box, thus giving great depth of hold. Vide the paper on "Construction and Ballasting of Yachts," in the Transactions of 1882, by Mr. T. Phillips.

more advantage than the fixed keel does a modern yacht with a deep cross section ; and often if, as the Americans say, the centre-board is out-pointing the keel yacht, the feat is probably more attributable to the sit and trim of the sails and to the manner of sailing than to the board, unless, of course, the keel yacht has a deficient area of longitudinal vertical section. Where the centre-boarder has the advantage is in lifting the board for sailing off the wind. By housing the board in a yacht like *Mayflower*, a reduction of about 10 per cent. is at once made in the area of immersed surface, and the effect of this is always manifest, especially in light winds or low speeds. However, so far as the *Thistle* is concerned, it can be taken for granted that Mr. Watson, whilst providing her with sufficient area of longitudinal section for lateral resistance, has so fashioned away the ends that she will give a good account of herself in any contest with American yachts, whether on or off the wind.

DISCUSSION.

Captain C. C. P. FitzGerald (Associate) : My Lord, I have been asked to open the discussion. I feel very unworthy to do so, although I may say that this is a subject I have taken a great deal of interest in all my life, ever since I was big enough to get into a boat. No doubt Mr. Dixon Kemp has hit on the secret of the whole question in alluding to the difference of measurement. The extraordinary shape of our yachts which we have arrived at now is of course due to the rule which we have been guided by of taxing length very little and depth not at all, so we have arrived at what a seaman cannot help looking upon as a monstrosity in the shape of a three-tonner carrying 7 tons of lead placed upon her keel. It cannot be for the advantage of naval architecture in any sense that it should be simply a case of a lead and sail balance, that the vessel should be more like an up-ended soap box, without any regard to the beauty of her lines or anything, but simply a question of how much lead she can carry and how much sail she can stick up at the other end of it. I, for one, shall hail with very great delight any alterations in these rules, which I understand are being made where sail area shall be taxed without regard to the total displacement of the vessel, for there will be no use putting sail up unless you can carry it. I am sorry that Mr. Dixon Kemp did not touch more upon our recent yachts of the *Chittywee* class, which seem to have opened people's eyes to the absurdity of going on on our present rules. He has touched on the *Thistle*, I am glad to see. There is one question which I should like to ask about the *Thistle*, if he can inform us. He says she is built somewhat on the type of vessels built some years ago, and also on the type of the American yachts which beat our vessels lately, but I see "14 feet depth of hold." I should like to know whether that is to the garboard or the extreme depth.

Mr. Dixon Kemp (Associate Member of Council) : She is built of steel. The lower part of the hull forms a sort of ballast box ; she has no floors like a yacht ordinarily would have, and the depth of the hold would be to the top of the lead.

Captain FitzGerald : She is something new, I imagine.

Mr. Dixon Kemp : The frames go round under the keel much the same as the *Vanduara's*, described by Mr. Phillips in Vol. xxiii. of the Transactions.

Captain FitzGerald: In the *Chittywee* I happen to know the keel is nearly half the width of the vessel. She scarcely "falls in" (from the top) at the side at all, but is exactly like a soap box turned on end. Now, with reference to the general question of building yachts, I have sailed a good deal about the world and have seen boats in nearly all parts of the world, and the conclusion at which I have arrived is that vessels are built to suit the special local circumstances they have to meet with. What is good in one sea is no good in another. I have seen every sort and variety of vessel, the Chinese boats, the Bombay boats, the Bermudian boats, and a great variety of others; the latter boats are the most extraordinarily built boats that ever one saw for speed, and yet very hard to beat in their own waters, although they were beaten last year by an American centre-board. The English type of yacht is a type specially adapted for the British Channel, where there is a short lumpy sea; and I doubt very much if those Americans had come over here and we had had any sort of bad weather and a British Channel sea, that they would have beaten the *Galatea* and the *Genesta*. I do not think they would. It was a regular smooth water race, a skimming dish race, and a nice breeze eminently suited for that description of yacht, and our yachts sailed under a great disadvantage. Mr. Dixon Kemp has given us here the displacement, on page 238. The displacement of the *Galatea* is 157 tons, and her transverse section of area is 114 square feet, as against 85 feet of the *Mayflower*, the sail areas being about equal; and it stands to reason that in smooth water you cannot shove that through the water with the same sail power as you do the other. In anything of a head sea I very much doubt whether the *Mayflower* would have been "in it." As I remarked at starting I shall hail with delight any change in the rules which will induce yacht builders, instead of making these shapeless masses full of lead, to go in for beauty and symmetry of lines, and all other things being equal I have no doubt we shall be able to sail against the Americans. We all know that Mr. Watson has been hitherto a very successful builder on the lines he has been forced to take up, and I sincerely hope that under the revised rules he will be equally successful, and will bring back for us the *America's* Cup.

Admiral A. F. R. De Horsey (Associate): My Lord, if I might take exception to Mr. Dixon Kemp's title, I should be inclined to say that I have been a little disappointed at its having been changed. I thought the title of the paper was to have been "A Comparison of American and English Yachts," and it has been changed to "Fifty Years of Yacht Building."

Mr. Dixon Kemp: Yes.

Admiral De Horsey: The only reason I mention this is, that the pith of the whole thing lies in the question of tonnage measurement for racing purposes. The Yacht Racing Association have discovered that their late measurement is not right, and they have tried to improve it. But, do the Yacht Racing Association deserve our confidence, and should they be allowed to lay down what the tonnage of yachts shall be, or rather, how it shall be measured? For some years past we have been sailing under their rules, and measuring our racing vessels by their length and breadth alone, and we have been taking no account of their depth or displacement. This absurd system of measurement induced narrow deep vessels, and culminated in a design for a monstrosity well named a "a plank on edge"—so contrived that, although carrying some nine or ten tons of lead in her keel, she only measured about one ton by Y.R.A. rules! So narrow was this vessel to be, that it was said a broad-shouldered man would have to turn edgeways to get below. The Yacht Racing Association, having maintained this faulty tonnage rule for some years, have now established a system dependent on length and sail area. I am not aware whether American yachts will agree to sail under this new

rule—if they do it will be fair for both—but nevertheless, I think we should take exception to a hard and fast rule of that sort, which takes only one dimension of a cubical body-length, and having applied to it the measure of sail area and an arbitrary divisor, calls the incongruous result tonnage, and binds the builder to be guided by those two measurements. I would ask whether anybody building a ship to catch a privateer in former days would have been content to limit the designer as to length and quantity of sail? Surely that would not be the way to get the fastest vessel of her size and cost. To take a more modern example: if you wish to build a blockade runner of utmost speed, would you not let the designer (provided he kept within the limit of size) select proportions and horse-power which would give the greatest speed consistent with other necessary qualities, or would you cramp his talents with limitations as to length and power? (for limiting the power of a steamship is much the same thing as limiting the sail area of a sailing vessel). To make matters worse, I believe that the Yacht Racing Association have established that this rule shall continue in force for five years to come. For five years we are to have a measurement which is vicious because it paralyses the two elements of length and sail-power, and takes no account of the two other essential elements of breadth and depth. Under such a system we cannot expect to encourage the construction of vessels best proportioned for speed. I should have thought that naval architects and also the great yacht clubs which enjoy certain privileges in consideration of the benefit they afford to naval architecture—would have rebelled against empirical rules which tend to fetter the talent of designers. This brings me to the remedy I would suggest—measurement by displacement. Until we accept the principle of displacement there will be no fair sailing between our yachts and those of foreign nations. There may be slight drawbacks to it, but it is undeniable that the *real* measurement of a vessel is the size of the hole she makes in the water. Under existing and late Y.R.A. rules, a builder ordered to construct, say, a 100 ton racing yacht has to devote his ingenuity, *not* to building the fastest vessel of the size specified, but to adopting such proportions and stratagems as will enable him to take advantage of the rules, by constructing a vessel to sail under a fictitious tonnage and thus get a large time allowance. It has been alleged that displacement measurement might lead to the construction of vessels having too little body compared to their length, breadth, and depth. I do not think that would result. Models do not prove much, but, as far as they go, I find, after three years' trial of a model regatta sailed by displacement (the number of pounds' weight of the model being considered her tonnage for time allowance), that the forms which have been built to be sailed in these races are not exaggerated in any respect. But, if the allegation be correct, I maintain that it is easy to discourage the construction for racing of unduly lean bodies by a rule establishing, that if the area of greatest transverse vertical section immersed be less than a minimum to be determined upon, then the tonnage of such vessel shall be deemed such as it would have been if calculated upon that minimum area. A co-efficient of ·053 multiplied into the length and breadth of a minimum area of immersed midship section would not apply this wholesome check to any vessel unless leaner than the celebrated yacht *America*, which vessel may be taken as the shallowest form English yachtsmen would tolerate. I do wish that naval architects would exercise their legitimate influence to bring about what appears rational, viz., that they should be allowed free scope, within reasonable limits, to build vessels as long, as broad, and as deep as they judge best for the tonnage required. This can best be done by adopting displacement tonnage, as has been done in the Royal Navy, the ships of which are now entirely measured thereby. I hope to live to see the day when we shall adopt it throughout the whole Mercantile Navy, so that a ship with a full cargo, a ship only partly loaded, and a ship in ballast shall each pay dues according to their respective displacement at the time. This is not connected with the paper before us, but I venture to mention it incidentally. It is so simple to have a displacement

diagram, by the help of which you would only have to go alongside a vessel and measure the distance from her plank sheer down to the water, and thus obtain her actual tonnage, whether for yacht racing, dock or other tonnage dues, or any purpose whatever, except for building and statistical records, for which the tonnage must always be a measure of cubical contents.

Mr. N. Scott Russell (Visitor): My Lord, I should just like to ask Mr. Dixon Kemp one question. Of course, in yacht racing there must be some measurement for time allowance. I should like him to tell us why the matter was complicated by introducing the sail area, when the length of itself alone would have given a basis for time allowance, and the shipbuilder would have been left free to make the best ship that could be built, whereas now he is again hampered, though in a less degree than under the old tonnage laws. I am afraid that if the displacement proposed by the last speaker were adopted we should get exactly back to the old miserable vessel, which would be long and narrow, and with enormous lead keels put in merely to balance the sail area.

Mr. B. Martell (Vice-President): My Lord, as a naval architect I entirely endorse what Admiral De Horsey has said, and I agree substantially with the remarks of Captain FitzGerald as well. I think it is simply lamentable, looked at from the professional point of view of the naval architect, to find that the Yacht Racing Association has encouraged as much as it possibly can the worst type of vessel it is possible to conceive. It has been very properly said it is similar to a plank on edge or to a capsized soap-box. This is to be deplored for many reasons. We know that the establishment of the Royal Yacht Squadron was for the purpose, to a great extent, of improving naval architecture. It was felt that those vessels competing with each other would improve naval architecture generally both for war-ships and also for merchant ships. No doubt it did so to a great extent. But this new rule altogether prevents that, because, although the old rule of allowing too much for the breadth of a vessel was no doubt injurious to a great extent, by taking the breadth and ignoring the depth, as in the old rule of builder's tonnage, yet, to dispense with breadth altogether, in my opinion, is far worse. I think that displacement should be an element in the consideration, and it is a most important element, in my opinion. The effect of the present type of yacht is that it has done away altogether with what was formerly the case when gentlemen built yachts for the purpose of comfort. If they build yachts now merely for comfort—yachts of decent form—they have entirely to dispense with the pleasure derived from the sport of yacht racing, because, to use a common expression, they are not in it. You are obliged to have a special machine built for the purpose, and those machines involve elements of considerable danger as well. The enormous amount of lead that is put on the outside of these yachts at the present time is a source of very considerable danger, unless very great care is taken. In the first place, it is exceedingly difficult to fasten it. Some time ago it was customary to fasten these lead keels with iron through-bolts, but the action between the lead and the iron, combined with the effect of the copperas water, the galvanic action which was set up corroded the iron bolts to such an extent that some of these yachts, when they were hauled up, showed that a bolt 1¼ in. thick was reduced to the size of a pipe stem. Had that yacht sailed for some little time longer, the great probability is that the bolts would have been eaten away entirely, the lead would have fallen off, and the vessel, having no stability, would have turned turtle immediately and drowned all on board. That, my Lord, I think is a point which requires considerable consideration now, the manner in which the lead keels are fastened to the wooden bottoms of yachts. They invariably should be fastened likewise with copper bolts. I think, if I mistake not, that Mr. Dixon Kemp rather disagreed with that on one occasion, but I hope that his experience has taught him to change his opinion.

Mr. Dixon Kemp: No; it was just the other way.

Mr. B. Martell: I apologise, because I thought that you did. I think most certainly a better type of vessel would be produced by allowing the displacement to enter in as one of the elements, that we should have more beauty of form, and should be able to indulge more, and with greater pleasure, in the art of the naval architect, in designing them, and I think that there would be a general benefit altogether; and I must say I cannot see very much difficulty myself why it should not be. I think, after the mountain labouring, as it has been, for a number of years to bring forth such a mouse as to merely take the length and the sail power, and to ignore all the other principal dimensions, is a very lamentable result to arrive at.

Mr. J. I. Thornycroft (Member of Council): My Lord, I would ask permission to make only a few remarks. I propose to look at the matter from an entirely different point of view—more from the point of view of a steamship builder. Admiral De Horsey has said that the displacement should be taken as a factor, and Mr. Martell also agrees with that. I think it is quite certain that the displacement is an important factor, and that we should consider it, but I think that Admiral De Horsey is wrong in saying that we should not impose any tax on sail area. The fact is that sail area is much the same thing as engine power in a ship. Admiral De Horsey is anxious that we should have beauty of form. If we are to have beauty of form, we want to drive as much displacement as we can at a given speed, with as little power as possible. Little power means little sail, and I think there is no doubt there should be a tax on sail. It is not a question I have considered much, but I do think we want to encourage large displacement with small sail area, because then we shall get well-formed vessels. I think we have to thank Mr. Dixon Kemp for laying the matter before us so clearly that any amateur on the subject would be able to follow it.

Mr. J. Inglis, Jun. (Member of Council): My Lord, there seems to be some consensus of opinion among the gentlemen who have spoken that it is a fact that yachts have deteriorated during the last fifty years, but I am not at all certain that this has been made out. I cannot recall any vessel which has been built within the last fifty years that I would care to possess in preference to such vessels as the *Amazona*, the *Irex*, or the *Marjorie*. I think those vessels I have named, and those Mr. Dixon Kemp has included in his list, can be called with great propriety sea-going vessels. The *Genesta*, one of the most modern, made her passage across the Atlantic and back without any accident. In the smaller classes what may be called an extreme type, having great length and great weight of lead keel, has no doubt obtained, but in the larger classes the real difficulty of handling such a vessel as the *Chittywee*, enlarged to 70 or 80 tons, is an effectual check on any extreme type of that kind being adopted. The adoption of so-called extreme types is not so much due to the action of the Yacht Racing Association, or any legislation with regard to measurement, as to the division of yachts into racers and cruisers, and it will be almost impossible to avoid the adoption of what some will call extreme types so long as racing is pursued with such ardour that it has become almost a profession. An old gentleman might keep a cob for his morning airing without thinking of entering it for a steeplechase, and so if we are to have racing yachts at all we must make up our minds to sacrifice a little comfort for speed. They are built for speed, and must have speed even at the sacrifice of comfort, and the enthusiastic sportsman will be quite ready to put up with a little discomfort for the sake of coming in at the head of a long string of racers.

Mr. Dixon Kemp: With regard to the question raised by Captain FitzGerald as to the depth of hold of the *Thistle*, and her registered tonnage, there is a foot-note on page 239 which bears on that.

Captain FitzGerald appears to have understood me to say that the *Thistle* was of the type of thirty years ago. That is a mistake. I did not say the type—but that the proportions—what the proportions of length to breadth were to those of thirty years ago. The discussion of measurement rules is rather beyond the scope of this paper, and I had no notion that it would be entered upon, but I should like to say a few words with reference to Admiral De Horsey's objection to length and sail area. He seemed to think it would be fair enough if the American yachts were rated by a similar rule. It so happens that they have been rated by such a rule for the last three years, and if any American yachts pay us a visit they will have to be rated by the same rule. I think Admiral De Horsey somewhat misunderstands the object of rating yachts. He condemned the new rating by length and sail area, because it placed a tax upon the two chief elements of speed; but it would be useless to rate yachts upon elements which bore no relation to speed or to success in match sailing. With regard to the rule fettering yacht designers, any rule to be of value as a test of merit was bound to be based on some element which bore a relation to the quality to be tested: otherwise the test would be absolutely valueless. There was no doubt that length and sail-spread were the prime elements of speed, and the designer was left in perfect freedom as to breadth and depth under the new rule. Of course, if he wanted a relatively long vessel, for any given rating, he would have to dispense with some sail; on the other hand, if he wanted a very large sail-spread, he would have to dispense with some length. The general objection to rating by displacement, which has been so greatly advocated for a long number of years, is this: that with two yachts of the same displacement one can be so very much longer and broader than the other, and thus be made to carry more sail, and in a little time we should have an extreme type of shallow boat just the same as we have under the old tonnage rule an extreme narrow type. The *Galatea* has a displacement of 167 tons. It is very certain that that 167 tons could be put into a longer, broader, and shallower form, so that a yacht anything approaching the type of the existing *Galatea* would never have the ghost of a chance against her at an equal rating of 167 tons. Displacement of itself is not an element of speed, but rather of slowness, and if the rating were based on it, the aim of the designer would be to use as small a quantity as possible for any given dimensions. That was the opinion of the leading yacht designers of the greatest experience; but of course it had not been proved, because the rating had not been used in this country. It has also at different times been suggested that what we know as the co-efficient of displacement should be used as the basis for a rating; or that a co-efficient, found by dividing the sail-spread by the displacement, should be so used. This latter method would meet the views of Mr. Thornycroft, that the test of merit should be the largest hull driven at the highest speed for any given sail-spread; but it is obvious that either of these ratings would produce what Mr. G. L. Watson, when discussing such a rule, described as a great "gutty hull," and in the end bring down the speed, as it would be useless building yachts which could attain the highest possible speed under the most favourable conditions for doing so, as their rating would be too high for them to succeed under other conditions. Mr. Scott Russell asked why the Yacht Racing Association had included sail-spread in the rating. It had been included for two good reasons among others: Sail-spread was the great controlling element of speed, and greatly added to the cost of racing. Increase of sail-spread meant extra cost for the sails themselves, and extra cost for the means of carrying them. A great outcry had been made that the expense of yacht racing was seriously interfering with the practice of the sport, and checking yacht building. Under these circumstances, it was considered wise to place a tax upon sails, but possibly that would have no influence in preventing a sail-spread being employed sufficient to develop the best qualities of a yacht in match sailing. So far as the rating by sail area of the Yacht Racing Association is concerned, it was adopted on the recommendation of the yacht designers themselves, and they

ought to be the best judges of what was most needed to meet the case, so the Association had really very little to do with it. The rating would appear to be capable of producing an endless variety of types, but the beauty of design, which Mr. Martell desired to see in yachts, depended upon the taste of the designer and skill of the builders in carrying out the design. The designer is practically left unfettered.

Admiral De Horsey: Not as to length.

Mr. Dixon Kemp: For any given rating, if he takes so much length he can do with a little less sail; if he takes more sail he must put up with a little less length. Gentlemen, I am extremely obliged for the manner in which you have received my paper, and I thank you all very much for your attention whilst I was reading it.

The President: Gentlemen, I am sure that you would wish me to convey to Mr. Dixon Kemp your thanks for his very valuable paper, and I may congratulate him upon the thoroughly useful and practical discussion that has ensued upon it.

ON THE CORROSION AND PROTECTION OF IRON AND STEEL SHIPS.

By Vivian B. Lewes, Esq.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

In 1822 the first sea-going vessel built of iron was launched in the Thames, and with this important era in the history of shipbuilding, the shipowners of the country incurred a fresh responsibility; as the use of the new material, while bringing with it innumerable advantages, also gave rise to the necessity for protecting the bottoms of the ships, not only from fouling, but from corrosion and rapid decay.

Under these circumstances, there slowly crept into the market a class of paints and compositions called protectives, some of which experience has shown to be fairly good, but in very few cases does any deliberate attempt seem to have been made to arrive at the cause, or causes, of corrosion, and to stop it by scientific means; and now, little more than fifty years after the general adoption of iron as a material for shipbuilding, it is, in turn, being replaced by steel, and with increased knowledge as to the strength of material, so is the substance of the plates being reduced, rendering their protection from the wasting process of corrosion absolutely imperative.

During these years science has not been idle, but the work done and the facts established are so scattered through the scientific literature of Europe, that few shipowners know much beyond the fact, that rust is an oxide of iron which, in forming, eats away their plates; and my object in this paper is to bring before the Institution of Naval Architects certain facts and suggestions which, I hope, may tend towards clearing up a subject of paramount importance to the first maritime Power of the world.

The first point that strikes one on approaching the subject of corrosion is the great divergence of opinion existing as to the relative rates of corrosion of iron and steel, which has arisen from the fact, that many of the experimentalists and writers on the subject have based their theories upon results in which metal, very different from any in actual use, has been placed under conditions which could not possibly befal the bottom of a ship.

In reviewing the work done on this part of the subject, it would be useless to go back more than twenty years, as before that, the iron and steel used were very different from those we have to-day, and in the same way the colossal researches of the Boiler Committee of 1874-78 throw but little light on the relative value of iron and steel as regards resistance to corrosion as it would affect a ship's bottom, their experiments being made under totally different conditions.

Much more to the point was a series of experiments tried in 1877-78 on the hull of the *Camel* at Portsmouth, in which naked plates of iron and steel were exposed under the same conditions and for the same period, with the result that there was hardly any appreciable difference between them.

In 1877 also, Sergius Kern, M.E., St. Petersburg, made some experiments on iron and steel plates, which are of especial value from the fact that the metals used were carefully analysed, with the following results :—

I.—Steel Plates.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon	0·290	0·300	0·180	0·234
Manganese	0.380	0·412	0·275	0·178
Su'phur	0·010	0·010	0·012	Traces.
Phosphorus	0·005	0·008	0 010	0·032
Silicon	0·015	0·011	0·010	0·021

II.—Iron Plates (Average Analysis).

	Per cent.
Carbon	0·110
Manganese	0·187
Sulphur	0·010
Phosphorus	0·004
Silicon...	0·008
Copper...	Traces.

These plates were immersed in sea water for thirty days, and the loss of weight carefully determined.

III.—Action of 100 Litres of Sea Water (Sp. Grav. 1·027) on One Square Metre of Iron and Steel ⅛ in. in Thickness.

Iron.	Loss in Grms.	Steel.	Loss in Grms.
I.	25·78	I.	22·75
II.	25·54	II.	22·34
III.	26·04	III.	21·83
IV.	27·44	IV.	21·96

In other words, that for equal surfaces exposed, the iron had lost by corrosion 26 grams, whilst the steel had only lost 22.

In 1881 Mr. Parker, of Lloyd's, read a paper on "The Relative Corrosion of Iron and Steel," at the Iron and Steel Institute, which is, perhaps, the most important contribution yet made to the subject, and his conclusions can be best summed up in his own words: "That so far as experience had gone, mild steel did not corrode, to any serious extent, more rapidly than iron under similar conditions;" and I think, from the evidence adduced, there is no doubt that in the slow processes of corrosion affecting a ship's bottom, steel is but little inferior to iron, although, in the former case, pitting and local action are more defined, whilst in the case of the iron the corrosion takes place more evenly over its whole surface.

The ordinary theory of rusting of iron in air or water is, that it is due to a great extent to the action of carbonic acid, free in the air and dissolved in water, and not to the action of moisture, or water and oxygen only; and this has been clearly proved by the fact that pure air, or water containing an alkali which will absorb all carbonic acid, has little or no action on iron or steel.

The iron is attacked by the moist carbonic acid forming carbonate of iron, and this is converted by oxygen into ferric oxide (rust), and the carbonic acid is again liberated in contact with the iron, taking up more metal; again the conversion into rust ensues, and the carbonic acid continues its career as middleman, dissolving up the metal and handing it over to the oxygen, until the whole of the iron is converted into a porous mass of rust.

This action takes place in air, and also most probably on abraded portions of a ship's side, close to and above the water line, where the plates, either by the chafing of chain cables and boats, or the trying influences of wind and water combined, have been denuded of their protective coatings; but anyone who has examined a vessel when in dry dock before her bottom has been touched, will have noticed a second kind of

corrosion, commencing first as little nodules, not much larger than a pea, under the protective and antifouling compositions, gradually forming a small water blister, which increases in size, and from being first filled with rusty water, gradually becomes filled with spongy rust, and finally blossoms out into a full-blown rust cone, often an inch and over in height, and covering pitting a sixteenth of an inch deep. These heavy rust cones are not generally evenly distributed over the whole immersed surface of the ship, but as a rule are most abundant on the rudder, near the stern, and below the bilge, whilst if they had been formed from carbonic acid, oxygen, and moisture in the same way as ordinary rust, one would have expected to find them evenly distributed from the water line to the keel, as both Mr. Buchanan and Tornöe, from their exhaustive experiments on the *Challenger* and Norwegian expeditions, agree that the amounts of carbonic acid and oxygen dissolved in sea water do not appreciably vary within the depth represented by the draught of a vessel.

Iron forms three well-defined compounds with oxygen :—

I. Black magnetic oxide or mill scale.
II. Ferric oxide or rust.
III. Ferrous oxide.

In the mill scale the iron and oxygen exist in the proportion of 168 parts by weight of the metal to 64 of oxygen ; in ferric oxide, which forms the basis of rust, 112 of iron to 48 of oxygen ; and in the ferrous oxide, 56 of iron to 16 of oxygen.

This last oxide has an intense affinity for oxygen, and will greedily take it from the air, being converted into ferric oxide ; but beyond this, ordinary processes of oxidation do not go, as the black magnetic oxide is only formed at an increased temperature, and, as might be expected from these facts, the rust formed in air, or where iron is freely exposed to the action of carbonic acid and oxygen dissolved in water, consists almost entirely of the ferric oxide combined with a certain amount of water.

In the same way, rust formed upon exposed portions of ships' plates under water also has this composition ; but when we come to examine the heavy rust cones, we generally find present a certain amount of the ferrous oxide, which suggests that the cones have been rapidly formed by some action which has not allowed time for the complete oxidation of the metal into ferric oxide.

It has been observed that when warm sea water acts upon metallic iron, a rust rich in this ferrous oxide is formed, and in 1882 the late Richard Cowper, on analysing a piece of the corroded surface condenser of H.M.S. *Spartan*, which had been in constant contact with sea water at a temperature of about 100° F., found that the corroded portion consisted of

Ferrous oxide = 42·33 per cent.
Ferric oxide = 2·21 ,,

and this great preponderance of ferrous oxide over ferric has been also noticed by Professor Liversidge in a piece of oxidised iron from the blade of a screw propeller which had been corroded in sea water at the ordinary temperature. (Proc. Roy. Soc. N.S. Wales.)

The unequal distribution of the rust cones suggested local galvanic action as a probable cause of their formation, but although in many cases the metallic constituents of the anti-fouling composition used rendered this probable, no metallic impurities could be found at the base of the cone or on the pitted portion of the plate to account for it, and under these circumstances it seemed probable that the galvanic action must have been set up by the rust itself, or, if set up by some speck of foreign metal, at any rate carried on by the rust.

It is a recognised fact, that the higher magnetic oxide of iron increases the corrosion of iron and steel by galvanic action, and it seems, therefore, probable that the ferric oxide would do the same ; and in order to see if the other oxides behaved towards the metal in the same way as the magnetic oxide, under the exciting influence of sea water, the following experiments were tried :—

Some steel plates, 4 in. by 1 in., were cut from the same sheet and were faced on one side ; on the polished surface of one a piece of thin blotting paper was laid, so as to entirely cover it and project ½ in. beyond its edges ; this was wetted with sea water and the other plate, with its polished face downwards, was placed on the wet paper, so that the two polished steel faces were separated by the blotting paper soaked with sea water. Wires were then placed in contact with the dry backs of the plates, and fixed in position by a dry wooden clamp. On connecting this couple with a " Sir W. Thomson's Marine Reflecting Galvanometer," a deflection of 20° on the scale was obtained. The upper plate was then raised, and its face having been smeared over with a thin paste of magnetic oxide, mixed with sea water, was replaced in position, giving a deflection of 112° on the scale. The plates were then carefully cleaned and dried, fresh blotting paper, moistened with sea water, placed in position, and the upper plate smeared with hydrated ferric oxide and sea water placed upon it ; this gave a deflection of 65°. Whilst hydrated ferrous oxide (made by precipitation and washing with well-boiled sea water in an atmosphere of coal gas) only gave a deflection of 25°, or very little more than the plates by themselves, portions of a rust cone treated in the same way gave a deflection of 110°.

In each case the reading was taken immediately the needle came to rest, and in all cases the current rapidly diminished, but generally recovered again on standing in circuit. A small cell made of crushed rust cones from H.M.S. *Inflexible*, after standing on short circuit for a week, gave a constant deflection of 108°.

These deflections were all much increased when sea water through which carbonic acid and air had been passed was used.

These experiments do not in any way establish the relative electrical relations existing between iron and steel and the oxides, a point which it would take months of careful research to fully clear up, but they do show that rust as we have it on a ship's bottom is quite as capable of setting up galvanic action as the magnetic oxide, even if the action be less intense, and in consequence somewhat slower.

Starting with these data, we can now explain the formation of rust cones and the resulting pitting of the plates. On the metal of our ship we have a small particle of moist rust, left there when the ship was last scraped, or else formed by a particle of some foreign metal or the perishing of the protective. The moist rust forms a galvanic couple with the iron and slowly decomposes the moisture, the oxygen oxidising the iron, whilst the hydrogen gently pushes up the protective and antifouling coats, forming a small blister, the sea water leaks in, an active galvanic current is produced, and the blister slowly fills with the result of that action—rust—and the continuation of the action gives us the large rust cones. This process being independent of the oxygen dissolved in the sea water and the amount of water present being small, the corrosion gives rise to the ferrous as well as the ferric oxide.

In many of these rust cones the structure is distinctly visible, and one can see that they have been built up in successive layers, each layer of rust as it has been formed pushing up the layer above it.

The larger number of cones existing near the stern and on the rudder may be induced by galvanic disturbances between the bearings of the shaft and the protectors, or to increased activity induced by the air and surface water sucked down by the thrust of the screw, whilst under the bilge they would be due to imperfect scraping.

It being therefore evident that corrosion of this nature is intimately connected with galvanic action, we can now see the points at which we must aim in order to check it.

We may arrange all the metallic elements in a series in which each metal shall be electro-negative to those following it, and whenever two metals are present in an exciting liquid and contact is made between any two portions of the separate metals a current is set up, with a wasting away of the electro-positive metal.

Iron is feebly electro-positive to its oxides, but zinc is strongly electro-positive to iron, so that when zinc is brought in contact with it in presence of an exciting fluid like sea water, the current flows from the zinc to the iron, and the zinc is oxidised, the iron remaining untouched; and this is what happens when zinc is placed in an iron or steel boiler, the galvanic relations between the zinc and the iron are so much stronger than those existing between the oxides of iron and the steel, that the oxides are ignored, and galvanic action takes place at the expense of the zinc.

Having now seen the nature of corrosion in our ships' bottoms, and the steps taken

to keep it in check in our steel boilers, let us see how far the protectives in present use are adapted for the purpose.

We may roughly divide protective compositions into three classes :—

(1) Red lead.

(2) Varnishes.

(3) Varnishes to which solidity and body has been given by an admixture of some foreign substance.

The first class owes the measure of success which is obtained to the fact that the red lead converted the linseed oil with which it was mixed, into a soap, which coated the metal, and so protected it; but its use has now nearly died out.

In the second class we find some of the most successful protectives, good gums dissolved in volatile solvents, which form a closely adhering varnish on the sides of the vessel, and which, if the plates are well cleaned and not sweating at the time the composition is put on, answer very well; but they are open to two objections. The gums which are good to use are expensive, and cheaper ones are often substituted, causing failure in the protection, whilst they have not sufficient body to withstand much wear and tear; and in the third class, this body is produced by the admixture of some foreign substance, generally oxide of iron.

From what I know of protectives, and from the facts I have brought before you, there is little doubt in my mind that the protective composition of the future will belong to this last class, and that it will be made by dissolving a good sound gum, not easily perished by sea water, in a volatile solvent, care being taken that neither gum nor solvent give rise to any organic acids; and body will be given to this varnish by finely divided metallic zinc, which can now be obtained in so fine a powder that it can be readily used as a pigment, and will give as good a body as oxide of iron can do.

Now in such a protective the varnish will act for many months, as in the case of many of our present compositions, and when in time the varnish perishes, as it must do from the action of sea water under pressure, then the zinc will set up galvanic action, and will prevent the corrosion of the iron by being itself the substance corroded, and the zinc oxide so formed will form a layer under the anti-fouling, and continue protecting the metal as well as many of the protectives we have in use.

Not only must we use our best endeavours to prevent nature destroying the steel and iron of which our ships are built, but we must remember that in a large number of our anti-fouling compositions we have present copper or copper compounds, and that if we use these we are imposing a still greater strain upon our protective, as any failure or fracture in its surface will cause a deposition of copper on the iron, set up strong

galvanic action, and cause serious pitting, a state of things which nothing but metallic zinc in the protective is strong enough to check.

The question of protectives is of very great importance to the Mercantile Marine, but of even more importance to the Admiralty, and at the present moment, with some of the protective and anti-fouling compositions in use in the Navy, it is no exaggeration to say, that in event of a naval war extending over any long period, when frequent docking would be impossible, one-half our fleet would be useless, as far as speed is concerned, before a year had elapsed, from the accumulation of rust, weed, and shell upon their bottoms; and I trust I may secure the co-operation of the members of this Institution in elucidating a question, which is of such vital importance to the well-being alike of the Royal Navy and Mercantile Marine.

DISCUSSION.

Admiral P. H. Colomb, R.N. (Associate): I am sure, my Lord, that anyone who like myself has been on duty into a great many docks, and visited a great many ships of very great varieties, must fall in entirely with the concluding remarks of the lecturer. I look upon the question which has been partly opened this morning as quite one of the most important, both for the Mercantile Marine and for the Navy, which can be discussed in this room. I do not think that the Mercantile Marine have as yet fully recognised its importance, and I am quite sure that until recently Her Majesty's Navy rather ignored it, and I think the reason is because the difficulties that are met with, are met with in a number of individual cases, and not in one large mass so as to startle or surprise one. The ship-owner is accustomed now to send his ship into dock, and to coat her with one or two coats of composition, and to do it, perhaps, every two or three months. It is a tremendous cost to him, and a tremendous loss of time, but it is all accepted generally as a necessary evil, and no steps are taken by the Mercantile Marine as a body to shake themselves clear of that great inconvenience and great expense. If you go away from this theatre down to any of the docks on the banks of the Thames, where steamers are being docked every day, if you wait until the water has left a steamer which is in dock, and you take your penknife and scrape down on the composition a little, I venture to say you may discover half a dozen different opinions registered on her bottom. You will see that there have been, perhaps, half a dozen different sorts of compositions applied at different times. In some cases you will find a difference. In some cases you will find shipowners who have steadily adhered to one particular composition, possibly not the best, but still one; and when you have penetrated with your penknife down to the bare metal, you will find no different opinions registered there. But the great point is that the question has never been treated scientifically. This is, I presume, almost the first really scientific paper which has been read upon this most important subject; and I do hope that this Institution will give more of its mind to that subject, not only for the sake of the Mercantile Marine, but for the sake of the Navy, because for the Navy, for the power of England, this question of the foul bottoms and the corroded bottoms is one of the very greatest importance. Any gentleman here present who happened to have looked back to the record of the Navy about the close of the seventeenth century might see how our fleets were eternally

hampered, and their one cry for what they called "clean ships." It was the one great cry of the whole Navy in those days, "Give us clean ships." Our ships could not pursue the enemy; they could not keep the sea; they had to be sent home to our ports to be what was then called "cleaned and tallowed." Now, if we do not keep our wits about us, and are involved in war, we shall have quadruplicated the difficulties which Sir George Rooke found at the close of the seventeenth century. The point which the lecturer specially drew attention to was corrosion, and especially the corrosion which we call "rust cones." My experience agrees with what the lecturer has stated, to the effect that corrosion does not appear to be greater on steel than on iron hulls; but I have noticed a very remarkable difference, which the lecturer touched upon, which makes corrosion apparently much more serious for steel hulls than for iron hulls, and that is, that the corrosion on a steel plate is more local. If you will cut away the rust cones from an iron hull, you will find under them an extended roughened surface; but if you do the same thing to a steel hull, as far as my experience goes, you will find a deep pit, quite small, that you can put your finger into. I have seen them not larger than the top of your finger in area, but perhaps as deep as $\frac{1}{8}$ in., or even $\frac{1}{4}$ in. And, therefore, it seems to me that it is more dangerous for steel hulls than for iron ones. My colleagues and I have been accustomed to classify the rust under three heads: there are the "rust nodules," of which the lecturer has spoken; there are the "rust patches;" and there are the "rust cones." The rust nodules have been described. They are generally small, dark nodules, just, as if it were, beginning. I am not so clear as the lecturer is that the rust nodules always develop into rust patches, and further develop into rust cones. I had myself rather the impression that the rust nodule was peculiar to certain compositions, and had not the same characteristics as the rust patches or the rust cones. But of all, the rust cones are the most serious. I have gone under a ship's bottom, and I have seen towards the stern, as mentioned by the lecturer, along the lines of the plates regular fringes of these rust cones as long as my finger, perhaps several hundreds of them, and under every rust cone there would be a very, very severe pitting. The patches are always on the surface, beginning sometimes with the size of a shilling, and sometimes rather less, and sometimes extending over very large areas; but, apparently, the corrosion never penetrating deeply into the iron, and generally doing no more than making it a roughened surface, so that if you passed your finger along over the bare iron on to the rust, and if you rubbed the rust away, you would find you were on a distinctly different surface from what your finger had been on before. I am quite certain that every one of us who were engaged with Mr. Lewes formed the same conclusion that he did as to the disadvantage of employing in compositions any such substances as would set up galvanic action of itself—such a substance, for instance, as copper, which has been mentioned; but I must own that I am glad to find from the lecturer's remarks that the natural history of the rust cone is not entirely due to substances in the composition itself. I had myself been of opinion that it was so; but I think once we know that the rust cone will develop simply from the galvanic action of the different statuses, if I may say so, of the oxides, that there will be some opportunity of getting hold of them, and getting rid of them. I strongly agree with the lecturer's remarks as to what the future of protective composition is likely to be. My experience entirely coincides with his in respect to that matter. I cannot, I regret to say, follow him in his excellent description of the chemical portion of the matter; but, so far as looking at a question of that kind with a practical eye goes, I do think that all inventors and makers of compositions (I do not know whether there are any in this room) had better take to heart his words, and go to work steadily on the lines that he has laid down.

Admiral Sir John Hay (Vice-President): My Lord, I do not wish to detain the meeting very long. I think this paper is of the greatest possible value, and the mode in which it was put before us by the

lecturer makes us very grateful to him for it. There are two objects in the application of these compositions. One is to prevent the fabric of your ship being destroyed, and the other is to have a clean bottom, so that you need not be under the necessity of having to go into dock. I should like to hear the lecturer, in his reply, give us a little information upon this point. I am no chemist, and I accept his statement that the particular composition which he recommends will be the protective composition for iron ships or steel ships in the future. I have no doubt that, as he predicts, it will have the effect of preventing the corrosion of the ship's bottom so long as it is protected by this substance, but the difficulty is this : that that which prevents the corrosion of the ship's bottom causes the substance to adhere to it which prevents the ship's sailing.

Mr. Vivian Lewes (Associate) : My Lord, may I be allowed to say that I have not been talking about anti-fouling at all. I have been talking about protective compositions. Anti-fouling is so important a subject that it would take a paper occupying not ten or twenty minutes in reading, but a paper extending over two or three hours even to give you the basis of the points which would have to be brought before you. I am merely talking this morning about the protection of the steel plates themselves, and I only hope that on some future occasion you will allow me to bring before you the results of some more extended researches into the subject of anti-fouling.

Sir John Hay : That being the case, my Lord, of course I would not detain the meeting. I would merely desire to say, on the particular point on which I was speaking, that I believe there is really no protection but copper, and that copper being attached to the wooden sheathing that is being adopted in some of our men-of-war. I know that that is a costly process, but a man-of-war is a costly object, and requires to be protected so that she can keep the sea. But as the subject is not to be further enlarged upon so far as anti-fouling is concerned, I shall not do more than record my opinion that no protection of iron or steel ships is sufficient for men-of-war unless it is also anti-fouling, and in my opinion there is no anti-fouler equal to a copper bottom on a wooden sheathing.

Sir Nathaniel Barnaby (Vice-President) : My Lord and Gentlemen, I had not intended to speak on the subject, although I have been greatly interested in the paper which has been read, but I have been induced to speak by what has fallen from Admiral Colomb. I think he is not quite fair towards the Royal Navy. I am sure he will regret that, if I can show it to be the case. But during the long time that I have known the Admiralty, one of the things that has given us more perplexity and trouble than any other is the question of providing a composition for the bottoms of iron and steel ships, and it is hardly fair to ignore the considerable chemical knowledge and large experience which have been brought to bear upon the question by such men as Mr. Hay, who was the Admiralty chemist at Portsmouth Dockyard for so many years ; by his successor, Mr. Weston ; by Dr. Sim, and by Mr. Farquharson. Now I am going to say at once that I see one reason why the matter has presented greater difficulties than it need have done, and that is, that almost everyone who comes to it with knowledge (and these men have come to it with large knowledge) gets some idea that he has found out something better than anybody else who has preceded him, and he begins immediately to lose our confidence as an adviser. He appears as the advocate of some particular system. I have always regretted that. I have told Mr. Hay many times that it would have been far better for him if he had continued to give the Admiralty the benefit of his experience and his advice, and had never allowed his name to be associated with any composition of his own. I gather from the paper which we have just heard that the reader of the paper has not taken up any such position as that which I have ventured to regret in the case of the gentleman whose name I have mentioned. If he will excuse me for saying it, I would almost venture to predict that he will not be touching it long, unless he is very

careful, before he falls into the same error. I am a much older man than he is, and if he will take my advice, and if he wants to help the Admiralty, and also those engaged in shipbuilding, he will keep his hands clear of the commercial part of it. If he can do that, he will be a real help to all of us. With regard to the use of zinc, I may say that while I do not know whether the use of zinc in the form advocated would tend to produce a certain roughness of the surface, I am afraid it would. Our experience with zinc plating upon the bottoms of ships has not been altogether favourable. I am myself more responsible than anybody else for sheathing the bottoms of ships with zinc plates. The *Audacious* and the *Bacchante* are two cases in point, and there are some others. The roughness which speedily comes on the surface of the plates interferes with speed, and although you absolutely preserve the iron, and you are never afraid that you may rub off part of your sheathing and expose the bare iron or steel to the evil influence of the sheathing on the bottom, as you would in the case of copper, yet the fact that you get this rough surface, and that your speed is interfered with, is a most serious drawback to that which I thought would be our great friend, namely, zinc sheathing. I think, my Lord, I have not any other remarks to make. I hope I have made it clear to Admiral Colomb that he is not fair to the Royal Navy when he says that it has ignored the question during so many years, and I may venture also to say this, that while I know Admiral Colomb is most interested in almost everything in Naval affairs and in throwing light upon everything he comes to, yet this is the first time I have known Admiral Colomb in connection with this subject.

Admiral Colomb: I do not know, my Lord, whether I may say a word?

The President: Only in explanation.

Admiral Colomb: It is only in explanation. In the remarks I made I did not mean to be hard on the Navy. I only meant to say that the Navy had not treated it scientifically. I merely meant to say that the Government had done just as the Mercantile Marine had done, and had registered its opinions in a great variety of compositions on a great variety of ships; but that it was only quite lately that they had attempted to deal with the matter as a scientific question.

Sir Nathaniel Barnaby: And that is what I have challenged, my Lord.

Mr. W. B. Robinson (Member): My Lord, I should like to be allowed to make a few remarks touching this important question. I happened to be at Portsmouth Dockyard for twelve years and more, and during that interval I personally examined something over three thousand ships and their bottoms, which were made either of iron or steel; and therefore I have a little knowledge of the subject from experience, although I have not been fortunate enough to have had a *carte blanche* to visit the whole of the Mercantile Navy as well as the Royal Navy, as Admiral Colomb has had. But I would like to remind him that during that interval I was stationed at Portsmouth Dockyard, when I had the help, in the first place, for a short space of time, of Mr. Hay and afterwards of Mr. Weston. I paid much attention to this subject; and, as Sir Nathaniel Barnaby has said, the Admiralty during my experience have always been very much alive to the importance of the subject, and always desirous of acquiring information on the point. The best coatings for ships' bottoms is a branch of an experimental subject. We all know some of the difficulties surrounding the circumstances connected with the preservation of metallic ships, from the fact that the elements forming the several compositions used are not often known: besides, a quantitative analysis of many things is impossible under the present state of chemical science. Then, I should like to say that there has recently been a report put before Parliament. I have read a few sentences of it, and, amongst other things, it touches upon this very question. The chemist at Portsmouth, to whom I have referred, is a very

clever man. He seems to have been given a kind of *carte blanche* to make a composition, but, judging by the evidence I have referred to, it would seem that his composition has entirely failed, or largely failed, at any rate; and I may say, *en passant*, that his composition—at any rate, in its *outer* coating, which we now are not to touch upon—is largely composed of copper. Now, we have here this admirable paper, and I hope that manufacturers of compositions will be able to take a hint from it. At the same time, I echo most heartily—looking to the advantage which the Admiralty hope to gain from chemical knowledge in this direction—the sentiment which has been expressed by Sir Nathaniel Barnaby, that the gentleman who has read this clever paper will not be drawn gradually into becoming an advocate for some particular system. What we want in this matter—as in many others—is more exact knowledge. Now, it has just been remarked by Sir John Hay, I think, that copper has always been found to be a pure anti-fouler. I wish only for a moment to be allowed to refer to that point. When I was in the Mediterranean, there was a paddle-wheel steamer, which, when she was docked, was found to be very much covered with barnacles and weed over her coppered bottom. She was a wooden ship, and she was scraped and made perfectly clean and bright under the personal directions of an officer on board; in fact, he showed the sailors how to polish a portion of the copper himself. That ship was docked a year afterwards, and came in perfectly clean; but in other cases it has been found that copper, after having been used for a year or two, and having once got foul and then brushed down, very rapidly fouls in all waters, as far as my experience goes, and notably so in the Mediterranean. I say here that we have been under a misapprehension—at least, I have been—for some time touching exactly what *rust* was. Now it has been defined to us in a more exact manner. I should like to refer to the first page of this paper, in which Mr. Lewes says that "few shipowners know much beyond the fact that rust is an oxide of iron which, in forming, eats away their plates." I did not know before that the rust which came from somewhere or other ate away the solid iron under it, and it seems to me that the gentleman who wrote the paper contradicts that afterwards, in saying that "in many of these rust cones the structure is distinctly visible, and one can see that they have been built up in successive layers, each layer of rust as it has been formed pushing up the layer above it;" so that it does not appear that the rust itself eats away the plate. As I said before, we want exact knowledge on this matter. At the same time, we do not want that the Admiralty, or the Mercantile Marine, should ignore the value of such gentlemen's opinions as have been mentioned by Sir Nathaniel Barnaby, notably the gentlemen at the Admiralty, and also the inventor of the composition who was referred to. We want more exact knowledge in this matter, in order that such knowledge may be applied to the preservation of the material of the ships of the fighting and mercantile navies of the country.

Captain J. D. Curtis, R.N. (Visitor): My Lord and Gentlemen, I would ask permission to refer you to an incident which happened some time ago. It has reference to an iron vessel which was sent to the African coast in 1848 about; she had copper pintles to her rudder, the result was that the gudgeons corroded, which was due to the galvanic action set up. I take it wherever galvanic action takes place there is no waste of iron, but the zinc varnish wastes. I think Naval officers and the Mercantile Marine may rest assured that if they only give these marine animals or animalculæ shock enough they will not adhere to the bottom. I have Admiral Selwyn's authority—not his authority of to-day but of thirty years ago—that as long as he had copper pintles to his rudder no accumulation of barnacles took place. The last time I was employed in the coast-guard, the watch vessel had iron pintles; the action set up kept the copper bright. I happened to be in Rio when the *Triton*, in 1862, came in with her bottom foul; she was a 9-knot vessel, and when she came in from the River Plate she was about a 5-knot vessel, so you can understand the importance of keeping the

bottom clean. The lecturer says, as far as I recollect, that zinc will waste away by reason of the galvanic action set up. I think the first anti-fouling composition was a slimy material, so that the bivalves could not adhere to it; when the vessel went through the water it perished, but the fault of that was that it got rubbed off and the iron deteriorated.

Admiral Sir JOHN HAY (Vice-President): My Lord, with the permission of the meeting, I would explain with reference to something that fell from Mr. Robinson, which showed me that I had not completely explained what I had desired to say on the subject of copper. I quite admit that copper-bottom ships have been fouled, but that is no reason they should continue so, because the action—as far as I understand it, the chemical action of the copper is such that the exfoliation of the copper either in fresh water or on the appliance of proper objects to clean it, relieves the copper at once of those marine animals that are attached to it.

Mr. J. FARQUHARSON (Visitor): My Lord and Gentlemen, I will detain you but one moment. In the paper we have heard read, on page 249, there is a statement of fact which I should like to call attention to, namely, an observation of the writer, who has been, I believe, looking into the subject to some extent lately. He says that iron corrodes more uniformly than steel. Now, that is exactly contrary to all my observations on the matter, and I wish to call special attention to it, because I fear that he has fallen into the error that other people have fallen into before, of comparing steel that was not steel at all, but steel covered with this black oxide scale formed against parts of the plates, in which case pitting will readily occur, for reasons which are perfectly well known. At Portsmouth the Admiralty had extensive experiments made to test this very point, with the result that steel corroded more evenly than iron when the mill scale was completely removed. I fear that some mistake has been made. I have hardly any other remark to make with regard to the paper, except to call attention to the rather important fact that there are many good protectives; there is no difficulty in obtaining a good protective; but there is a difficulty in keeping it on, and the expedient which has been recommended will be liable, I presume, to the same difficulty in keeping on as the others. Metallic zinc in a minute state of division has no adhesion, and its success will depend on something added. It has been tried with no great success already by the Admiralty, and unless we are told how to apply it with more probability of success in keeping on, I do not think we shall have gained very much by having attention drawn to it. It was applied a few years ago and failed. Those, I think, are the only remarks I need detain you with.

Mr. C. F. HENWOOD (Visitor): My Lord, there are a few remarks I should like to make on the observations of Sir Nathaniel Barnaby, as to the result of the experience of the Admiralty with zinc sheathed ships. I will call the attention of the meeting to the fact that the system adopted by the Admiralty is one that is not likely to lead to the best results, inasmuch as the zinc is not brought into direct galvanic contact with the iron, and also that an insulating material in the shape of wood planking is interposed between the zinc and the iron. Gentlemen here know perfectly well—at least, those old enough to remember the days of wooden ships which were sheathed with zinc—that the zinc sheathing had no effect whatever in preserving from fouling such wooden ships. They got as foul as iron ships do at the present time. The like result was found in the case of marine boilers with respect to corrosion. Zinc is known as an electro-positive metal to iron, and it was introduced into steam boilers——

The PRESIDENT: You will forgive me interrupting you, but we are not going into the question, which is not raised by the paper, of anti-fouling. You must confine yourself to the subject-matter of the paper, and that will be in accordance with our rules.

Mr. Henwood: The subjects are so connected together, my Lord, that one can scarcely separate the two, but I will avoid the subject of fouling as much as possible. The object of putting zinc into marine boilers was to prevent corrosion, and for some time pieces of zinc were placed promiscuously into the boiler, and very little effect was derived from doing so, but when the zinc was brought into galvanic or chemical contact with the metal of the boiler, the best results were obtained—at the sacrifice, of course, of the zinc, which has to be renewed periodically. The tubes of the boiler, and the boilers themselves, last about three times as long as they do without zinc so applied; but it is necessary that the zinc should be brought into direct galvanic contact with the iron. I have here a sample to illustrate the case. Here is a piece of bright iron plate; it is protected with zinc on each side. That is screwed up perfectly tight, the bolt, also of bright iron, fitting closely to the hole in the zinc and the iron plate, so that you get the proper galvanic contact between the two metals. This specimen has been immersed in a solution of sulphuric acid for a considerable time, and when taken out the iron was perfectly protected and as bright as when inserted in the solution, and there is not a trace of rust on it; but it is at the expense of the zinc, which, as you may see, has somewhat wasted away.

The President: Might I ask you to keep yourself strictly to the subject-matter of the paper, or else we shall get into difficulties.

Mr. Henwood: It is on corrosion, my Lord, that I am speaking now—the corrosion of the boilers. All I wish to add is this, that when zinc, as is proved by the case of the marine boiler, is brought into direct galvanic contact with the iron of the hull exposed to the action of salt water, there is complete protection to the iron or steel.

Mr. F. K. Barnes (Vice-President): I should just like to say two or three words on the question raised by Mr. Henwood. Mr. Henwood appears to be under the impression that the way we applied zinc to the bottoms of ships in the Navy was such that the zinc did not come in contact with the iron of the bottom.

Mr. Henwood: Galvanic contact.

Mr. Barnes: It was in contact—galvanic contact. Of course, the zinc was not put over the whole of the plating of the bottom, but we thought that we had just put sufficient in contact to keep the bottom clean, without eating away the zinc too rapidly. That was what we attempted, and that is what we thought we had done. In fact, in one of our latest experiments we were completely led astray by the results. The *Audacious* was coated with zinc, and she went to her station at Hull. After remaining afloat at Hull she came to the dockyard for examination, I think, as many as three times, in perfect condition, and we thought we had settled the whole matter—we believed that the zinc answered the purpose for which it was intended thoroughly, and it was a very cheap material, and offered perfect protection to the iron and immunity from fouling. Well, that ship went to another station; but, unfortunately, when next taken to a dockyard for examination she did not come in clean. On the latter station she was in salt water, but on the other she was in the brackish water of the Humber. The latter circumstance led us completely astray. We thought we had prevented fouling, but we had not. Again, if you put zinc on the whole of the bottom you will find another very startling result. There was a patent taken out by Mr. MacIntyre, of Newcastle, for sheathing ships with zinc; and a ship was coated with zinc on his plan. I believe she went out to the East Indies—to Calcutta—and she left most of her zinc, with the exception of three or four sheets, somewhere in the water, and did not bring it home.

Mr. Henwood: Would you kindly explain, Mr. Barnes, how the zinc in that case was brought into metallic contact? I do not understand that.

Mr. Barnes: Simply in this way: the large heads of the bolts that fastened the wood sheathing came out to the outside and touched the zinc.

Mr. Henwood: Is that all? That is not galvanic contact.

Mr. Raylton Dixon (Member): With your permission, my Lord, I will call attention to a fact that occurred to me during the discussion of this paper, and that is, that we have had a great deal of discussion on the question of anti-fouling, which, as you have once or twice pointed out, is an entirely different matter to that of corrosion. I have also been struck by the omission of any allusion to this question of corrosion in the interior parts of our vessels. So far as my experience has gone, the difficulty we have to deal with is in the interior, especially those parts in the neighbourhood of the boiler —the most inaccessible parts, where there is the heat also to affect it; there is very great difficulty in preventing corrosion, and in steel, so far as I have seen from one or two cases, there would seem to be even greater danger than in iron. I have asked you to kindly allow me to mention this, because I should like Mr. Martell to give us some of his experience on this question. Mr. Martell will remember one instance which I allude to, where a vessel built of steel only eight years ago happened to come to the Cleveland slipway for repairs, and she was found to be greatly corroded in the bunkers, underneath the engine seats, and the water ballast chambers near to the engine-room, showing that the heat there had been a cause that had had serious effect on it; the steel had corroded to an alarming extent. The flanges of some of the angle irons had entirely disappeared, and the tie plates were eaten away in holes. It certainly did not bear out the statement made by the writer of this paper, and the experiments he alludes to as to the corrosion of steel compared with that of iron. I hope that Mr. Martell in his remarks will give us the benefit of his experience, and his recommendation with regard to that, because I have come to the conclusion, that to avoid this the most likely thing seemed to be the application of some bituminous coating or cement, such as is applied to a great extent in the Navy.

Mr. B. Martell (Vice-President): My Lord, I had not intended to say anything on this question had not Mr. Farquharson made some remarks with reference to what Mr. Parker, my colleague, had stated, and in the absence of Mr. Parker, I think it only just to him that I should explain. Mr. Farquharson appears to think that Mr. Lewes quoted Mr. Parker's words when he said, "I think, from the evidence adduced, there is no doubt that in the slow processes of corrosion affecting a ship's bottom steel is but little inferior to iron, although in the former case pitting and local action are more defined, whilst in the case of the iron the corrosion takes place more evenly over its whole surface." That is not a remark of Mr. Parker's, but that is the inference drawn by Mr. Lewes. Mr. Parker only says this, that so far as his experience has gone steel did not corrode to any serious extent more rapidly than iron under similar circumstances. I think Mr. Farquharson lost sight of the inverted commas showing where the quotation ended. I thought in the absence of Mr. Parker I should just like to explain that. Now, my Lord, I agree with Mr. Raylton Dixon that the discussion of this subject seems to be somewhat going off into a wrong channel. Mr. Lewes has already explained that he does not in his paper deal with anti-fouling compositions, and therefore it is not fair to him to begin to discuss this question from this point of view, when Mr. Lewes tells you that he did not come here to read a paper on anti-fouling. But he has promised us on some future occasion to do so, and I am sure we shall all be very pleased indeed to hear it. Now this is a very important

paper, and a very important subject indeed. It is a question which, although Admiral Colomb seems to think the owners of mercantile ships have not given any attention to, I can tell him that they have given the greatest attention to it for years and years, and I can assure him they are constantly giving attention to it, and if anyone can find out an anti-corrosive or anti-fouling composition that will answer the purpose required, he will become one of the millionaires in this country—no doubt about that. Now with reference to the comparison between the corrosion of steel and iron. I should be very sorry if in one case—one isolated case—where corrosion was seen to occur more rapidly with steel than with iron, that that should cause any great distrust of steel and that it should shake the confidence of owners of steel ships, because we must bear in mind that "one swallow does not make a summer." We have at the present time a great many steel ships which have been running for eight or nine years, and therefore in judging of the comparative qualities of these two metals we must take the whole subject into consideration rather than base any inference on one isolated case. The case mentioned by Mr. Raylton Dixon was certainly somewhat peculiar, I must admit. We had an intimation from his locality that there was a vessel undergoing repairs in which there was an amount of oxidisation, or rather, an amount of deterioration, that had gone on to a very alarming extent, and the matter was considered of so much importance that I was instructed to go down to see this ship, which I did. I may say, to confirm what Mr. Dixon says, that throughout the length of the side bunkers on both sides of the vessel, the frames and the reverse frames, as he says, were eaten away to a very alarming extent. In some instances the whole of the steel had gone altogether; the stringers, the keelson, part of the double bottom and fore and aft deck tie plates had wasted away very considerably. That vessel was about eight and a half years old. But we must look at the circumstances attending that before we come to a conclusion with reference to the rapidity of oxidisation in steel as compared with iron. I may say it came out on investigation of the matter that the coal bunkers—I think I am right in saying—had not been coated since the vessel was launched; and the abrasion caused by the coals being put into the bunkers, as you can easily understand, left the surfaces of steel quite exposed. I could not, as I say, gain any information that the inside of these bunkers had ever been coated since the ship was launched. And in the next place, in putting coals into bunkers we know they are put in wet and dry, and there is nothing that deteriorates either iron or steel so much as a condition of wet and dry on the surface of it. This had been the case, and there was something in addition to that also, which was alluded to by Mr. Farquharson, and which has been also alluded to by Mr. Lewes, which bears on this question. The vessel was one of the first built of steel, and on looking at a portion of the interior plating at the after part of the vessel where it had not been coated with paint or anything else, in a perfectly dry place, and where oxidisation had not taken place, you could see the mill scale on it just as it came from the rolls. We know a very great deal more now on this subject than when this vessel was built—that this black oxide, if left on, will in connection with moisture soon set up galvanic action, which will cause a very rapid deterioration, and I have no doubt in my own mind that the great wasting in this was owing in a great measure to that cause. That was, in my opinion, one cause. The other cause, as I have shown, arose from gross negligence. What can any owner expect, if he fails to coat the surfaces of iron and steel? The action would be the same inside where the surfaces are wet and dry, as it would outside of the bottom if you neglected to coat it for eight years. You cannot wonder at very rapid oxidisation taking place and wasting in that manner from such negligence, and from such causes. I must admit it was the first case I had seen of such considerable wasting in steel, and it somewhat altered the opinion I had previously formed. Up to that time I had been of opinion that the wasting of steel was not more rapid than of iron, but I could not help thinking that when the steel is worked of fine scantlings, and where parts such as angles project from

the surface and are not continuously coated, oxidisation soon commences, and it would appear that the wasting goes on more rapidly in steel in that case than it does in iron. When it first commences, it appears to honeycomb the fine edges where there are projecting parts, and oxidisation goes rapidly on, eating away the steel almost like dry-rot in wood. That goes to show the great necessity of paying attention to the coating of steel vessels, even to a greater extent than iron. I believe in the case of steel it is more important for two reasons. In the first place, owing to the superior strength of the material, you get smaller scantlings allowed, and the oxidisation takes place more rapidly in comparatively small scantlings than in large scantlings; and in the next place, the effect is comparatively more injurious to the strength of the ship when you have small scantlings. All which goes to show that you must pay more attention to the coating of these steel vessels even than in those built of iron. If that is done, if constant care is taken, then there is no more danger to be feared, and no more risk attending it, than there is with regard to iron. I quite agree with Mr. Dixon that there is one point deserving of attention, and that is, whether it would not be more desirable, instead of using ordinary paint in coal bunkers, where you are so subject to get the surface scraped off from coal being put in and taken out, if you could use some kind of hot asphalte, or black varnish, or some composition of this kind. I know we used to do that years ago. I remember about fifteen years ago a firm in London used to build ships on the Tyne, and their invariable practice was to use hot asphalte for coating the surfaces in the bunkers. The material used to be taken down hot in pails and thrown inside of the bunker plating until it became quite hard like hard enamel, that lasted for years. I think that owners of steel ships in particular should know that this is a matter of very great importance, and that it is desirable a coating of that sort should be used in bunkers where there are not many opportunities of seeing the surfaces. As I say, coals are put in wet and dry, and when greater deleterious action takes place, greater precaution should be taken. I should be very sorry, as I said before, if because of this one case shipowners should lose confidence in steel. I do not myself think there is anything to fear. I have heard that some chemists think where there is a greater proportion of manganese in the metal the deterioration takes place more quickly. We had the steel in question analysed, and it did not turn out that there was more manganese in it than was generally used. We endeavoured to ascertain from the steel manufacturers whether there was any peculiarity in the manufacture, because there was one remarkable thing in it, and that was, that although the projecting portions, the stringers and the frames, &c., were in some parts eaten away to the extent they were, the inside of the plating was not wasted away at all; it was not even pitted. Therefore, I do not think with ordinary care we have anything to fear.

Mr. S. J. Mackie (Visitor): My Lord, I should like to trespass upon the meeting for a few moments, and I will confine myself in my remarks as much as possible to the points to which I understand you have limited us, that is, the corrosion and protection of ships. I should like to say at the outset that I am not interested in any composition, nor am I in any patent or system in regard to such matters, although I was more than twenty-five years ago awarded by the Society of Arts a silver medal for a paper I read at one of their meetings. I should like in the first instance briefly to refer to fouling, in one sentence; that is to say, the fouling, whether of iron or steel plates, is to a large degree a zoological question, and it is exceedingly important in all cases where plates are tested in salt water that the seasons of the year in which the vessel has been should be noted. The spring season is the germ season, both for the marine animals and plants which attach themselves to ships' bottoms, and the cleanliness of the hull will more likely be due to her voyage not having encountered the germs.

The President: Will you please to confine yourself to the subject of the paper.

Mr. Mackie: The fouling only takes place in the germ season. As to corrosion, the iron or steel must be completely protected by a perfect, unbroken coating from the action of the air or the sea, and the metal itself must not be allowed to develop galvanic connection. In various experiments made on iron and steel, I have found that difference in the qualities of the angles and plates of iron or of steel will exert decided corrosive influence and oxidisation, and wasting will be set up. Therefore, if a composition or a varnish is to be effectively applied to a ship, it must be one which is tough and coherent, and will not give rise to fissures or cracks; because, if it does so, galvanic action will assuredly follow through the access of the salt water to the iron through those cracks and fissures. A great deal has been said about the use of a variety of materials in the protective composition. It seems to me that the whole subject at this time is not treated scientifically; and although it is a scientific subject, and most deserving of being brought before this meeting, I must say that it seems to have been treated with an entire absence of those scientific principles which ought to be the basis of its consideration. With regard to the protection of the iron by varnish, I cannot conceive how the admixture of oxides of any metals, zinc, iron, or copper, can act detrimentally upon the protecting effect of the varnish on the ship, because the oxides of the metals are non-conductors. They are not the best non-conductors, certainly, but they are non-conductors. I believe it is quite possible to show that the oxidisation of copper in a protective composition would not convert the ship into a galvanic battery. One of the chief points to which I wished to draw attention was that it must not be considered that steel as steel, or iron as iron, will of itself give satisfactory results. If the metal were perfectly homogeneous it might be so, but irons and steels are always mixed metals, and thus contain in themselves the elements of evil. I had some years ago to deal with strong acids. On one occasion a new tank was put up made of cast-iron, with wrought-iron framing. The galvanic action was so severe that in the course of three or four days the acid was leaking out of the tank and running on to the ground. What I wanted to draw attention to was that as long as combinations of metals are used in a ship, whether of iron or of steel, it must be expected that rusting will act variously and differently, in accordance with the extent of the qualitative differences of the metals.

Admiral A. F. R. De Horsey (Associate): My Lord, I will not detain the meeting on a subject which requires a clever chemist to speak upon, and which is beyond my competence; but I wish to draw attention to one point on which I think the meeting will agree with me. We learn from the paper that the lecturer has read to us that up to the present time we have not succeeded in finding any thoroughly protective medium to put on our ships. Some day we hope we may, and until that time comes there is all the more reason for using such compositions as we do possess to their best advantage. According to my experience, the protective paint is not generally well put on. It is often done by contract, on a low estimate, which is hardly conducive to good work. The labour of scraping the old paint and rust off a ship's bottom (much of it overhead work) is excessive, and where this is not properly done, the composition, put on over a scale of rust, or where the iron is not perfectly clean, cannot be expected to preserve the bottom. The wearying labour necessary to prepare such large surfaces to receive the protective paint leads me to think we require some inventive genius to contrive a machine to supersede manual labour in thoroughly cleaning ships' bottoms, so that the protective composition may be in close contact with the bare iron.

Mr. Le Neve Foster (Visitor): My Lord, there is one point that has not been yet referred to, and which I should wish to bring before the notice of the meeting, as it appears to me to be of primary importance with reference to the use of any protective composition. I perfectly agree with

what Mr. Farquharson has just stated, that the difficulty does not so much lie in obtaining a protective medium to put on the iron, as it does in keeping the protective on when once applied. We are aware that with all new ships, in spite of the iron being pickled and, presumably, the acid killed, protective compositions never give such good results as after the ships have been at sea, been docked, and recoated; and it would therefore appear that the state the iron is in when the protective is applied, plays a most important part. If I remember rightly, the attention of the Admiralty was particularly called to the failure of protective compositions, from the scale on the plates, in the case of H.M.S. *Iris*, some five or six years ago, and that it is since that date that their invariable rule has been to have all plates carefully pickled before use. It would, however, appear that further action takes place after the pickling process, in spite of the acid having been presumably killed, and which has on several occasions been observed in ships of the Royal Navy. Only last year H.M.S. *Amphion*, when in dock, showed marked signs that some action was still going on. It is the care that appears to be necessary to thoroughly kill the acid after pickling, with lime water or some other neutralising agent, that I would wish to draw the attention of the meeting to, as in many instances, I fear, sufficient importance is not paid to this question, and it is one of the points Mr. Lewes in his very admirable paper has not touched upon.

Mr. W. W. Beaumont (Visitor): My Lord, may I just call the attention of the meeting to a paper in the Transactions of the Institute of Naval Architects, read in 1872, by Mr. R. Mallet, F.R.S., which deals not only with some of the aspects of this question, but gives experiments extending over 300 days; and, as far as corrosion is concerned, it deals with the matter from the chemical point of view, the electro-chemical point of view, and the metallurgical point of view. It takes metals of various kinds in contact with various metals, and with the sea water in different conditions of purity and salinity.

The President: We are much obliged to you for calling our attention to it, but we must not go into that paper.

Mr. Beaumont: I should like to suggest that those interested in this subject would find in that paper a great deal bearing on the subject which is being discussed, going into this subject far more completely than it has been gone into to-day, and dealing with a great many more of the numerous conditions involved in the question.

The President: No doubt the meeting will be much obliged for the reference.

Mr. Vivian Lewes (Associate); Gentlemen, in reply to the remarks you have been good enough to make on my paper, I have but little to say; but there are two or three points which have been raised in the discussion which need explanation. One of the last speakers has called attention to the presence of mill-scale on the plates, and the process by which it is removed. I took it for granted that this question had been finally settled many years ago. It was then distinctly proved by Mr. Parker, Mr. Martell, Sir Nathaniel Barnaby, and others, that black mill-scale was at the root of a great deal of the serious corrosion which took place on submerged iron surfaces, and that it was absolutely essential that it should be entirely cleaned off before protective compositions could be put on with any chance of success; and I believe Sir Nathaniel Barnaby will bear me out when I say that in all cases in the Navy where "pickling" in dilute acid has been used for this purpose, every possible precaution has been taken to "kill" the remaining acid and remove all traces of sulphate of iron; lime-water and weak solutions of other alkalies being used for the purpose, it being well known that any trace of acid or sulphate of iron will set up rapid corrosion and pitting. Sir Nathaniel Barnaby has called our attention to the roughening effect produced on the iron and steel

plates by the use of zinc sheathing, and other speakers have dwelt on the practical failure of this kind of sheathing as a protection for any long period against the action of corrosion on ships' bottoms, a result which, I think, was to be expected from the rapidity with which zinc would oxidise and waste away under these conditions; but all the speakers have lost sight of the fact that I do not rely upon the zinc coming into action until the varnish protective has perished—it is a device to prolong the period of protection. In the present protective varnishes containing oxide of iron, when the varnish perishes the oxide aids corrosion; whilst, in the kind of protective I suggest, no galvanic action can be set up as long as the varnish is intact, because it will insulate the zinc; but when the varnish, by long exposure, has perished, then the zinc will commence to act galvanically, and a further period of protection will be afforded the iron. Another very important point which I had not intended to mention, until speaking of anti-fouling compositions, is that I consider it absolutely essential that the outer, the anti-fouling composition, should have as its groundwork the same varnish as the protective, as it is simply absurd to use, as is done in many cases, a different kind of varnish having a different degree of elasticity and expansion, which can only result in loosening, blistering, and falling off of the compositions. If, on the other hand, you have the same varnish as the basis of the anti-fouler, then it also acts as a protective, and has to be perished and washed away before the protective proper begins to be attacked. This also prevents the gas generated by the galvanic action of the zinc blowing off the composition, as the coating must be porous before the galvanic action is set up, and so allows the escape of the generated hydrogen. Mr. Robinson has drawn attention to the experimental difficulties of the subject, a point which certainly cannot have impressed anyone more deeply than it has me, and the chief difficulty, or, rather, one of the chief difficulties, is the impossibility of getting any two ships docked, cleaned, and coated under similar circumstances. Half a dozen ships coated with the same composition may be sent to the same waters, at the same time of year, and for the same period, and yet, on again docking them, no two will be found to be in exactly the same condition. A great deal of this arises from the fact that very little attention is paid, especially at our dockyards, to the way in which the compositions are put on, and the condition of the plates at the time when it is put on. In a ship where you have large masses of metal rapidly changing temperature—changing temperature much more rapidly than the damp air of the dock which surrounds it—you are always liable to deposition of moisture on the metal, to sweating, and you might just as well throw your composition into the sea as attempt to put it on to a ship in this condition. Another most pernicious practice in vogue in our dockyards is the scraping down to the bare metal, which takes place each time a ship is docked, no matter how sound or good the protective may be; when you have have got a sound and firmly adherent coating of protective, which only needs the perished anti-fouling composition scrubbing off, be thankful for it, and only scrape to the metal where the protective is faulty or loose, or where corrosion has commenced, and at these spots take special precautions that every trace of rust is removed, for, as sure as any remains, there will corrosion start and pitting ensue, the dangers of which are fully dealt with in the admirable paper by Mr. Mallet, referred to by Mr. Beaumont. In the Mercantile Marine this excessive scraping is a thing of the past, with the result that the protection of the ships is far better than that of the Navy. Mr. Robinson has also referred to the scientific work of Messrs. Hay and Weston, and the compositions they have given to the Navy, and, much as I appreciate the great services and admirable work which these gentlemen have given to the service, I do not think that Mr. Weston would wish his name coupled with the "Admiralty composition." Also, chemists, like doctors, do not always agree, and in both the compositions mentioned compounds of copper play an important part; and, although I am prepared to admit that

copper compounds form admirable anti-fouling compositions, yet I have seen so much damage to vessels arise from their use, that, personally, I do not think they ought ever to be employed with iron or steel ships. I understood Mr. Farquharson to say that, in my experiments with steel and steel coated with the various oxides, I had not taken into consideration the presence of black magnetic oxide of iron; but in all my experiments, as I point out in the paper, carefully faced and polished steel was employed, no particle of black oxide remaining. Mr. Farquharson also tells us that zinc, in the finely divided metallic state, has been tried in the Navy, and without success; and he would do me a great kindness if he would give me further particulars of these experiments, as I have been looking for some such records for a long time, and have failed to find any. In our torpedo boats galvanising is now being extensively used; but, I believe, it is found that the galvanised zinc surface interferes with the cohesion and sticking on of the compositions, so that when the vessels go quaking and shivering along at high speed, much of the composition flakes off. Another drawback being that, in case of any abrasion of the zinc, the galvanic current set up rapidly causes the oxidation and destruction of all the zinc, and leaves the iron bare. For these reasons, I think a varnish protective containing finely divided metallic zinc would succeed better than galvanising with zinc, as it would offer a better foundation for the anti-fouling composition, and, in case of injury to the surface, would not be thrown off by galvanic action. With regard to the subject of interior corrosion, that has been so ably treated by Mr. Martell, I need say nothing, except that I entirely agree with all he has said. Mr. Mackie has pointed out that the use of steel and wrought iron together produces a galvanic current and rapid corrosion, a fact brought home to every shipowner who has seen the rust-cones formed round rivet-heads, often resulting in the latter being entirely eaten away; indeed, if you consult Mr. Mallet's paper, you will see that different parts of the same plate are capable of setting up galvanic currents. And now, Gentlemen, it only remains for me to thank you for the kind way in which you have received this short chapter in the history of corrosion, and to hope that, on some future occasion, I may be allowed to bring before you the wider subject of "fouling."

The President: I wish, Gentlemen, on your behalf, to thank our friend Mr. Lewes very heartily for his most valuable paper. It was quite obvious that this was a subject of immense and paramount interest to every owner of a ship, whether a merchant ship or a ship of the Royal Navy, and I only regret that the mystic hour may have a little tended to curtail the discussion of it. It was evident that that discussion must be a long one, and it has proved most interesting to us all. I am sure I may tender your thanks to Mr. Lewes for his admirable paper, and I also think our thanks are due to Mr. Beaumont for calling your attention to that which you may not have otherwise remembered. I will repeat the words, because they may not have been heard distinctly. He informed us that we should find this subject discussed at considerable length, or treated of at considerable length, by Mr. Robert Mallet, F.R.S., in the year 1872. It is so long ago that it is just as well as to awaken your memories to it, and you can all refer to that paper. That may be for your convenience. The chemical knowledge which our friend Mr. Lewes has displayed, has largely tended, no doubt, to elucidate the difficulties of the question, and I am quite sure that everybody who has heard him will go home a wiser man on the subject than he was when he came into this room, and be able to profit by his remarks.

FUEL SUPPLY IN SHIPS OF WAR.

By Sir N. Barnaby, K.C.B., Vice-President.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

I have made no public statement of any kind concerning the excess in draught of water in ships for which I am largely responsible. That there is such excess has been stated over and over again in Parliament and in other public places by members of the Government.

I have felt that if the ships were defective, as has been alleged, no talking or writing would make them better; and if they were not, then I could afford to wait for the establishment of the truth.

I had not intended to take the opportunity which our annual gathering offers for referring to subjects of current professional interest, and only decided to do so when the Council asked me to take up some question which might be profitably considered.

I shall confine myself almost exclusively, in the short paper I propose to read, to one of the classes of ships which have been referred to recently in Parliament, viz., to the *Impérieuse* and *Warspite*.

It will be seen that the question of fuel supply underlies the case, as it does that of the other vessels which have been said to be too deeply immersed.

To make the matter clear, I will give at once, as it was officially given to me, a comparative statement of promise and fulfilment in the case of these ships.

H.M. Ships "Impérieuse" and "Warspite."

	As designed.	"Impérieuse" as completed May, 1886.
	Tons.	Tons.
Weight of hull	3,574	3,700
,, armour and backing ...	1,501	1,505
,, machinery	1,210	1,316
,, armament	365	525
,, coals...	400	400
,, general equipment (430 men)	550	(507 men) 569
Total tonnage ...	7,600	8,015
	Ft. in.	Ft. in.
Mean draught of water...	24 11	25 10½
Depth of armour below load water-line amidships	4 9	5 8½
Height of armour above load water-line	3 3	2 3½
Speed in knots per hour	16·0	17·1

The 11½ inches excess in draught of water is made up mainly of three items :—

Excess on hull	127 tons, or 3½ per cent. on the original estimate.	
,, machinery	106 ,, 9 ,,	,,
,, armament	160 ,, 44 ,,	,,

Concerning this excess the First Lord of the Admiralty has informed Parliament as follows :—

"At the time the design was passed, sufficient allowance was not made for the number of complement, weight of guns, machinery, and engines. If fuller consultation had taken place between the designer and the officers responsible for these weights and details before the ship was laid down a more accurate estimate could have been made, and the extra weights afterwards found necessary would have been anticipated. Regulations insuring this co-operation have now been made."

Then follow regulations providing for consultation between the Director of Naval Construction, the Engineer-in-Chief, and the Director of Naval Ordnance.

On this point I do not wish to say more than that the Engineer-in-Chief was always responsible for estimated weights of machinery, and the Council of Construction, of which

he and I were members, accepted the changes in boilers from locomotive to ordinary type (for half the whole number) for sufficient reasons. We knew that this would increase the weight considerably. As to the number of the complement, that is always settled by the First Sea Lord, in conference with the Council of Construction, and the Director of Naval Ordnance, and I have no doubt it was so settled in this case. As to armament, the Director of Naval Ordnance always furnished the estimate of weights, and informed the Constructors of the growth of demands for increased weight.

He, the Controller, and the First Sea Lord concurred as to the design in all its stages.

His first estimate was for guns of 9·2 in. of 18 tons. The guns actually made for the ship were 9·2 in., but they are 24-ton guns.

The final result is stated by the First Lord as follows :—

"With the important exception of being more deeply immersed than was anticipated, the *Impérieuse* in her trials fully realized the expectations of her design. Notwithstanding her deep draught, she is now, taking the essentials of speed, armament, and armour into consideration, if not actually the most powerful, one of the most powerful iron-clad cruisers afloat of her tonnage."

The deeper immersion to which he refers is not, however, the 11½ inches coinciding with the 400 tons of fuel, but that caused by an increased coal supply.

With 400 tons of fuel the ship has a knot higher speed than was promised, her main deck gun ports are more than 12 feet out of water, and the barbettes over which the heavy guns fire are from 20 to 25 feet out of water.

As to stability, she may be immersed 20 inches deeper, with 900 tons of fuel, and she has a range of 84 degrees. To so lofty a ship 11½ inches is an insignificant extra immersion.

Lord George Hamilton goes on to say :—"The principle adopted by successive Boards of Admiralty since 1870 of selecting as their legend weight of coal, in new ships that they proposed to build, an amount considerably less than that which the bunkers were constructed to carry, originated when compound engines began to be used in Her Majesty's ships.

"The substitution of improved engines for the older types effected such an economy of fuel in relation to the engine-power developed, that a very much less quantity would carry a ship so fitted the same distance as a ship of identical form and size with the simple engines previously in use.

"This seems to have influenced the Admiralty to accept, when designing new ships, as the legend weight of fuel, a quantity which gave as great a radius of action as was possessed by earlier ships, though it was at the same time decided to provide for exceptional conditions by the construction of reserve bunkers.

"Thus although the position of the belt may have been correctly calculated for the

weight of coals it was at the time decided to carry, and which was adopted as their deliberate policy by the then Board of Admiralty, the same is undesirably low if coals to the full stowage (which is the policy of the present Board) are put on board."

It comes to this, then, that the ships are designed according to the policy of one Board of Admiralty, and their conformity with the design is to be tested by the different policy of another Board.

This is exactly what has been done. The whole question of whether 400 tons was to be the normal quantity of fuel, and 900 tons the bunker capacity, was debated before the ships were begun.

When they are completed, and after their responsible designer has left office, a new Board refuses to accept the 400 tons, and puts 900 tons on board for the trials of the ship.

Anyone who will take the trouble to go through the tables of the ships of war with side armour of other European navies, will find that the entire coal capacity does not exceed about seven per cent. of the displacement at load draught of water.

This would give the *Impérieuse* 560 tons for her full bunker capacity. No one can contend that the coaling facilities for British ships are inferior to those possessed by other Powers, or that for fighting on equal terms with other ships there is any reason why they should carry more fuel.

But the Board of Admiralty is not content with the *Impérieuse* as being in fighting condition until they have added to this amount in fuel a weight equal to that of the designed armament of the ship. Can anyone contend that the whole weight of the armament of an armoured ship of war can be wisely added in fuel after she has on board as much as her rivals?

Or, take the case of the *Admiral* class. Their proper full bunker capacity, judging from the most recent French ships, would be 700 tons. But their bunkers will hold 1,200 tons. According to the policy we are considering 500 tons will be added to that carried by their rivals. This 500 tons would have enabled us to increase the armament of the ships by 60 per cent. at the load draught of water. Who in designing a ship would deliberately increase the fuel in this manner?

What he might do is to provide as much space for fuel as possible, taking care not to sacrifice efficiency, and remembering that fuel can be made to assist in giving stability and in resisting shot as truly as, although less efficiently than armour. This it was the deliberate intention of the Board of Admiralty of 1881 to do.

This policy the present Board declines to accept. It fills the bunkers, and then objects that the ships are evidently deeper than had been anticipated.

One would have thought they might have said, "These bunkers are far too large for the ship. The former Board was prepared to accept for occasional use the deep immersion caused by filling them. We are not prepared to do this. Paint out the

words 'Reserve Bunkers' and use the cellular spaces for another purpose, or leave them empty."

Or take the 5,000-tons class, in which it is said that in first going to sea the top of the belt will be below the water. I should not have objected to this immersion, but the Board of Admiralty does. It states the case as follows :—

"The designs for the belted cruisers were prepared in 1884, and the sketch design received the final approval of the Board of Admiralty during that year.

"It was intended that, with all their legend weights on board, they should have a mean draught of 21 ft., and that 18 in. of the armour belt, which is 5 ft. 6 in. in width, should be above water.

"After the designs were approved, tenders for the construction of five vessels were invited. Some of these tenders provided for the substitution of triple expansion engines of 8,500-horse power in place of the compound engines of 7,500-horse power originally contemplated, and the advantages of the offer were so manifest that it was decided to adopt this type of engine for all five ships.

"To compensate for the increased weight entailed by these engines, and in view of the economy in fuel that would result from their adoption, it was decided to reduce the legend weight of coals to be carried by 60 tons; this placed the legend weight of coals at 440 tons, in place of the 500 tons originally approved.

"The extra weight of the engines, of increased complements, and of armament, amounting in all to 186 tons, increased the draught of the ships by 7 in., placing the top of the belt 11 in. out of the water.

"It appears to have been decided, although the bunkers of these ships were constructed to hold 900 tons of coal, that 500 tons (afterwards decreased to 440 tons) should be taken as the amount they were to carry under ordinary conditions—in other words, as their normal supply of fuel.

"It was calculated that this amount of coals would carry the ship about 4,500 knots at 10 knots an hour, and with this the Board of Admiralty at that time appear to have been satisfied.

"The present Board, however, are of opinion that it is far preferable that ships should carry to sea with them the largest amount of coal they are able to carry.

"If the whole of the 900 tons, with the additional weights alluded to, be placed on board, instead of 440 tons, the top of the belt will be, on the ships first going to sea, 6 in. below the water."

I have no copy of the legend or drawings of these ships, and I have received no communication of any kind relating to them. These charges and statements are made without notice of any kind given to me or to Mr. Barnes by their Lordships.

As I am not in a position to question the facts, I will accept them, and, with your permission, put the case in another way.

These are armoured ships, *i.e.*, they have side armour. They are of 5,000 tons displacement.

I shall show that the French ships of recent type—*Bayard*, *Turenne*, *Duguesclin*, and *Vauban*—which are of near 6,000 tons displacement, only carry 400 tons of fuel, according to the most authentic public statements, and that the average amount does not exceed seven per cent. for such ships generally.

This would give 350 tons. With this supply, notwithstanding the extra weight of triple-expansion engines, of increased complements, and of armament, said to have been accepted, there would still be nearly 15 in. of belt out of water, instead of the 18 in. originally designed.

The bunkers provided to hold 900 tons may be regarded as follies, if you please. You may issue an order, if you attach any importance to the question, that the belt is never to be more deeply immersed. But I say to you, that to issue such an order would be very unwise.

There is no magic virtue in having some of the armour above water in these ships. Some heavily armoured foreign ships are deliberately designed with the top of their hull armour several feet under water.*

* The way in which the design for these ships of the *Undaunted* class (the belted cruisers) was worked out was something like this. We had two ideas of the way in which ships of such small size as they are might best be protected. One was by way of what is called "avoidance," that is, by having the protecting armour which is to cover the engines and the boilers and the magazines placed beneath the water by intention in the first place, so that it should be difficult for the shot to get access to it, and then to subdivide the space above that depth and below the first deck above the water by iron divisions, and to place within it fuel and a certain amount of cork at the sides. We should have commenced by placing deliberately the deck which is to cover all our vital parts below the water, as it is done in very large foreign ships, and in a good many built in England. Above that there would have been the divisions coming up to the deck a little above the water, and coal stowed above and below that deck. I did not like that. My own preference was greatly for a deck starting above the water; and so it came about that we agreed to start with a deck 18 in. above the water. I was myself in favour of finishing the protecting deck by sloping armour at the side, there being coal bunkers between this deck and the upper deck, divided into compartments. But it was considered by those whose judgment had as much right to be weighed as mine, that the better way to finish the protecting deck was to put a piece of vertical armour at its edge, and so they became "belted" cruisers, as they are called, instead of being like ships building now everywhere, that is, ships without any armour on their sides. They would have been, in one case, ships with internal armour exclusively, instead of being, as they now are, ships with side armour. That will explain the sentence I have just read, that "There is no magic virtue in having some of the armour above water in these ships. Some heavily-armoured foreign ships are deliberately designed with the top of their hull armour several feet under water."

The Board statement is to the effect that the practice of providing bunker space, beyond the quantity of fuel intended to be usually carried, dates from 1870, and is due to the introduction of compound engines.

This is a mistaken idea. The following ships, and many others having this peculiarity, were designed before 1870, and have not compound engines :—

	Authorised Complement.	Capacity of Bunkers.
	Tons.	Tons.
Swiftsure	450	540
Triumph	450	550
Audacious class ...	450	500
Inconstant ...	680	750

Other ships, not having compound engines, present the same features, such as *Devastation*, *Thunderer*, *Belleisle*, *Orion*, *Hecate*, *Gorgon*, *Shah*, and *Northampton*.

The larger bunker provision was made to carry a larger quantity of fuel for an exceptionally long voyage, without having to upset the usual arrangements on board; and certainly not with the intention of always carrying the larger quantity.

The effect of the new regulation upon future designs can only be to reduce the size of the coal bunkers, and to abandon the utilization of cellular spaces for the stowage of coal. Such cellular spaces are indispensable for limiting the inflow of water; and the exclusion of coal from them, when an extended voyage has to be performed, is to be regretted.

The supply of fuel I have indicated as being that carried in modern ships of war of other navies may seem to some persons too small. No one can say whether or not it will prove to be sufficient for the exigencies of a naval war.

The ruling fact is, that no more of the weight of foreign ships at their load draught is devoted to fuel than the amount I have given; and my contention is, that this, and not the opinion of any sailor, shipowner, or other person, however eminent, should decide the quantity for British ships.

I furnish some examples as given in the Tables of Lloyd's Register.

TABLE A.—Total Capacity of Coal Bunkers in recent Foreign Ships of War, having no Sail Power, and with Steaming Speeds on the Measured Mile of 14 to 15 knots.

	Displacement in Tons.	Coal Capacity in Tons.
Custoza	6,850	580
Tegetthoff	7,270	650
Bayard	5,880	400
Turenne	5,880	400
Duguesclin	5,780	400
Vauban	5,780	400
Caïman	7,120	500
Indomptable	7,060	500
Requin...	7,060	500
Trident	8,670	540
Colbert	8,460	590
Redoutable	9,030	610
Courbet	9,500	600

I attach also a comparative statement as to cruising ships in our own Navy of earlier date than the *Impérieuse*:—

TABLE B.

	Monarch.	Sultan.	Impérieuse.
	Tons.	Tons.	Tons.
Displacement	8,320	9,290	8,000
Total weight of armour ...	1,364	1,480	1,445
Main armament	4 25-ton guns, in two turrets.	8 18-ton guns in broadside.	4 24-ton guns, in 4 barbettes.
Speed in knots	15	14	17
Fuel { Authorised complement	600	600	400
Fuel { Bunker capacity ...	630	810	900
Description of engines ...	Simple, one set.	Simple, one set.	Compound, two sets.

I hope I have succeeded in showing that the deep lading of the *Impérieuse*, of which we have heard, is due to a deliberate departure from the conditions accepted by the Board of Admiralty for which she was designed. Whether I have also succeeded in justifying the policy as to fuel supply upon which she was designed I leave to your judgment. In my opinion it was a sound policy, and that which has been established in its place is unsound and injudicious.

DISCUSSION.

Admiral A. F. R. De Horsey (Associate): My Lord, as I have only just had the paper put into my hands, and as, I am sorry to say, I lost the opportunity of hearing the first part, I am afaid that the observations I wish to make will not be of much value. I understand that a paper on side-armour is to be read to-morrow morning, and it will be better, perhaps, that I should not touch upon it now, that being a matter of very great interest to Naval officers. I would merely say this, that I go a great deal with Sir Nathaniel Barnaby. I do not see the necessity for cramming a ship up with every bit of coal that she can be made to stow. I think it is a very valuable thing to be able to put five hundred tons more coal in, in order to enable the ship to make a long passage. If the ship is less able to fight during that time, it is a misfortune, but it must be put up with in return for the great advantage of her being able to make the passage. Whilst the advantage of a large fuel supply cannot be over-rated, a ship (rightly, or wrongly) designed to carry only a small proportion of coal should clearly not be habitually overloaded so as to render her protective armour nugatory.

Captain C. C. P. FitzGerald, R.N. (Associate): My Lord, I am afraid I shall get into the position that Mr. White feared, of having his voice too much heard in this Institution, but as I suppose the great guns will reserve their fire until the small ones have had a crack at the enemy, and damaged him a bit, and then bring their heavier metal to bear upon him and sink him right off, perhaps your Lordship will have no objection to my having a shot at him from a six-pounder. There is one point which I may take hold of, and on which I have the misfortune to differ from Sir Nathaniel Barnaby. It is a very simple question, and admits of a very simple answer. He says, "The ruling fact is, that no more of the weight of foreign ships at their load draught is devoted to fuel than the amount I have given; and my contention is that this, and not the opinion of any sailor, shipowner, or other person, however eminent, should decide the quantity for British ships." I look upon that contention as absolutely untenable. The amount of coal which is good enough for foreign ships has nothing whatever to do with the amount which is good enough for English ships. The sphere of our action will be totally different. Many foreign nations will simply fight close to their own coasts, and will endeavour to intercept our communications, and they will be able to go into harbour and coal every second day if they like; but our position is very different from this. Our possessions are so extended that we require quite a different proportion of fuel, and even if we have to sacrifice some other useful quality, it is essentially necessary that British ships should have a larger supply of fuel than any other foreign nation which we could mention. On that point I beg entirely to differ from Sir Nathaniel Barnaby. I consider it is incontrovertible that that is so. Then as to the subject of armour I shall hope, when the paper is read to-morrow, to be allowed to say a few words, because I am at issue on the principle of what I may call internal armour, and very low armour, as I cannot see the reason of it. With regard to the belt, the very men who designed these ships tell you that

they do not depend for the stability of the ship upon side-armour. If so, what is the good of it? My belief is, that ships must depend for their stability upon side-armour, and carry the belt right fore and aft, and not stick a short bit in the middle. If it is no good for that, it is no good at all. That is all I can say on the subject. I, of course, mean with reference to the stability. It is distinctly a stability question. The "non-capsizability" of the ship—if you want a long word—is dependent considerably on the armour, in the French ships. We are told that if they have this armour only 18 in. or 2 ft. above the water it would have no effect on stability, that the water will come in above it, and that she will turn bottom up in happy company with her enemy. This I do not believe if the belt is complete and the covering deck above water.

Admiral P. H. Colomb, R.N. (Associate): Following, my Lord, the excellent rule laid down by the last speaker, that the small guns should fire off their little shot before the heavier guns come forward, I would ask to be allowed to say a few words. I am sure, my Lord, that no one in the Navy feels more than I do the position of a modern naval architect. I think that I recognise that whereas he was formerly a designer, such as the designer of Mercantile Marine ships now is, his greatest efforts in connection with war-ships are made, not in the way of design, but in the way of invention. There is a horrible word in use in the dockyards which conveys the sense of invention, and conveys with it also a sense of the terrible trouble that there is round the head of the naval architect—in the dockyards they call invention "scheming." We have heard from Admiral De Horsey an opinion coinciding with much of that which fell from the lecturer, and I presume that between my friend and me there will be found that difference which is always found, happily, where Naval officers exist, viz., a friendly difference; but I do not agree with what fell from him, and therefore I am not in agreement with a great deal of that which fell from the lecturer. But one thing I do feel very deeply in my heart, and that is, that the British war-ship should always be in a mean condition for action; she should not be sometimes very much worse and sometimes very much better, but she should be always, as I say, in a mean condition for action. I hope I do not misunderstand Sir Nathaniel Barnaby in taking the opposite view that she should be sometimes very well fitted for action and sometimes not so well fitted. I applaud greatly his remark at the beginning of his paper, that fuel underlies the whole question which has recently been so much debated in Parliament, and part of which has been brought before us to-day. It is a question of fuel, but it is also a question of weight, and I am not one of those who, in these questions, is inclined to throw the whole of the blame upon the naval architect. In my little sphere I know that I have had to take blame myself, and I know that in the Navy we also have to take blame, and the blame that we have to take is in this way: that we are desperately fond of calling upon the authorities to put things into our ships, but we are very strongly averse to ever letting anything go out of them. I may tell you a little anecdote that happened to myself shortly after I woke up to this condition of things. It became my business; this question of putting things into a ship and taking things out was forced upon me, and I laid down for myself the position that I always would make as gallant a fight as I could that nothing should ever come into a ship unless an equivalent weight went out in some form or other. I remember that in one ship, while I was walking along the deck in the dark, I barked my shins against a very large and massive object which was lying in the gangway. I called for a light, and I found that I had barked my shins against a very heavy iron anchor stock. I found it had been for some time an inconvenience in the ship; there was no place to put it. My attention was directed by this circumstance to the question of heavy iron anchor stocks generally. I found that most of the ships had them, and there was always a difficulty about them; nobody knew where to put them. I collected evidence, and I made as gallant a fight as I could in order to get rid of these anchor stocks. It was a little thing I hoped to do. We

had a great debate, which went round all the yards. Every Naval officer in them had something to say to it. The Admiralty had something to say to it. I think I had the whole of the Constructors at my back, but we were quite unable to carry it, and the anchor stocks remained. The argument was that the ship would be imperilled if you took away an anchor stock, though it could not possibly be used until after the peril was over. The carrying of a spare anchor stock means that you must have lost your first anchor stock before you want to use it, and then you have had your peril, so to speak. *A few weeks afterwards we parted quite readily with a whole anchor and cable out of most of the ships that I tried to get the anchor stock out of.* There we were. We could not get rid of the small things, but we got rid of some of the big things. I think the public should clearly understand what part the Naval Lords and the Controller can take in the details of designs. It has been suggested that they can take a very large part. Anyone who understands Admiralty business, and who knows what looking into drawings and designs is, ought to understand that the attention which the Controller or any of the Lords of the Admiralty can give to details must be very, very small, and that they are therefore bound to consent, sometimes it must happen that they must consent, before they have thoroughly gone into the subject as they would have done had they had more leisure. I observe a tendency in the paper, which appears also in the statement of the First Lord, to follow up the economy that we get in engines by reducing the coal supply, by continually shortening the coal supply so as to keep a steady radius of coal power to save your weight at the expense of your capacity for locomotion. I do not agree with that, but I must say that I think the lecturer makes a point when he speaks of these ships, that he has mentioned, being built on one policy and judged on another. I think that perhaps it may be said that Sir Nathaniel Barnaby has not been quite fairly treated on that point. I must say that I do sympathise with him in that, although I quite think that the original policy was as wrong as it could be. Sir Nathaniel Barnaby says there is no reason why they should carry more fuel. Now, I speak as one who has commanded a ship with a good coal supply and good sail power; I have commanded another ship with a very bad coal supply and very bad sail power; and I have commanded a third ship with no sail power but with a first-rate coal supply. Now, if you ask me which of those ships I would rather go to war in, I should tell you the last. I cannot think that any person could accept Sir Nathaniel Barnaby's statement who has felt what I have, and what I know other officers have felt too, in reference to this question of the short coal supply. It was the occasion of the very first angry words between my Admiral and myself. I won't say angry words, because we never had any angry words, but on my proceeding to China in a flag ship, the first nearness to angry words between my Admiral and myself arose on this question of our coal supply. We were both sore and afraid of trouble and mischief of some kind, and though he did not lose his temper, I lost mine. And I can tell you that no man who has had the experience I have had, and has found himself, as I have found myself, with the Russian scare on at Hong Kong and not coal enough in the ship to steam direct to Singapore against the wind, when I knew, or at any rate believed, that the Russian ships had that capacity, would be inclined to agree with the lecturer on this point.

Sir Nathaniel Barnaby: What ship?

Admiral Colomb: The *Audacious*. I am reminded also by that, that the *Audacious* is one of the ships mentioned here as having empty bunkers, that is to say, having an authorised capacity of 450 tons, but an actual capacity of 500 tons. I don't think we ever got 500 tons into the ship, but while I commanded her we never had empty bunkers. Moreover, we carried them where we ought not to have carried them in order that we might get a proper supply. When we talk lightly of the coal

supply in this way, we forget that to-morrow we might be at war, and have to keep blockading squadrons established off the enemy's ports. Those ships will be continually using their coals in false alarms of all sorts, and if they have a short coal supply a blockade cannot be maintained, and your trade will suffer. On that ground I think that you cannot possibly exaggerate the importance and the necessity for a very ample coal supply. I hope, my Lord, I have not been too long, but I am afraid I am taking up a great deal of time. There is one very practical point to which I should like to call the attention of the meeting; it has reference to the question of coal supply in time of war. Do you recollect that the *Shah* could not pursue the *Huascar*, so that she could not follow up her intentions, because she had to go elsewhere for coal? I rather wonder that fact has not been recollected, yet there it is in the official despatch. I do not think from this point of view that French ships, or any other foreign ships, are a proper standard of comparison for us. Our standard of comparison must be geographical. We have a certain empire to defend; certain routes to traverse; certain highways to keep clear; certain points at which we must be at a given time, and that is the British standard of comparison, and no foreign standard, French or other. I regret that Sir Nathaniel Barnaby should have apparently spoken of designed immersion as the same thing as undesigned immersion. I think it is a pity that he took that line. There no doubt are ships designed to have their armour under water, and they are, as I said before, in mean capacity for fighting a battle in that condition. But I do not think it is quite right to draw any comparison between ships in that category, and such as are designed to have their belts a foot more above water than they are found to be when the design is completed. I think, my Lord and Gentlemen, I have said all I have to say on the point. I hope I have not detained you too long.

Admiral De Horsey: May I explain a slight misconception on the part of my friend Admiral Colomb.

The President: It must be only by way of explanation.

Admiral De Horsey: It will be purely explanation. My friend Admiral Colomb has said that he did not agree with me in the opinion which I expressed just now about Sir Nathaniel Barnaby's paper, but I think he misunderstood. The point I wished to make clear was, that I agreed with Sir Nathaniel Barnaby, that a ship which was designed to carry 400 tons odd, should not necessarily be made to carry 900 because she happened to have that space vacant. As to whether the ship was properly designed to carry only that small amount of coals, I did not express any opinion. If you ask me, I should say decidedly not. There is one more explanation, my Lord, that I should like to make. Admiral Colomb has mentioned the *Shah* as having been unable to pursue the *Huascar*. I can only tell him that nobody felt more than I did the importance of a supply of coal at the time of the Russian scare, when I had to go all the way from southern latitudes to high northern latitudes to look after the Russian squadron. But it is not the fact that the *Shah* was unable to pursue the *Huascar* because she had no coal. We were never stopped by that. We did go in to take in a few tons of coal, but that was owing to our having spare time on our hands.

Captain H. W. Henderson, R.N. (Visitor): As a Naval officer I feel it is my duty to back up what Admiral Colomb has just said regarding coal supply, and to protest against the views enunciated by Sir Nathaniel Barnaby. I am certain if he was to poll the Navy to-morrow, he would not get a single Naval officer to agree with him on this point. A good fuel supply is to a fleet, squadron, or single ship what transport is to an army; they are helpless without it; on it depends their mobility, their power to strike well-directed blows, and readiness for emergencies. Without a reserve of mobility,

armament however powerful, armoured protection however great, are valueless; ships are reduced to helpless logs, fit only to crawl from one depot to another, whose first thought on putting to sea is to edge for the nearest port, unfit and unable to act decisively upon any information they may receive. There is nothing that will invite disaster, and inevitably lead to loss of confidence among officers commanding ships, more than deficiency in this respect. Possessing inferior armament, armoured protection, and even speed in some or all respects, than an opponent, one knows what to do, possibilities may be calculated, something may be left to chance and good luck, much to pluck, discipline, and training, but without a decent reserve of motive power, ships intended to go to and keep the sea can neither do nor dare anything. Constant coaling is necessary, and dirty work for the crew, more especially as practically no consideration is given to the subject, and no facilities or fittings for doing it rapidly and effectively are provided. It takes fully a day to clean and put to rights a ship after she has finished. Until this is done she is unfit to go into action, or does so at great disadvantage. In my opinion fuel supply and speed are the most important considerations in the design of a ship; they should not be sacrificed to any other factor, and in the balance which must be held between them, coal endurance should not give way even to speed. My experience is that a satisfactory mean between the sailor and naval architect will never be hit off until the latter, during some part of his career, goes to sea, and becomes practically conversant with the behaviour and conditions of all classes of ships in all weathers and climates; also of the requirements demanded from them by the ever-changing aspects of naval warfare in all parts of the world. The individual who designs ships should, of all people in the world, understand their management and control.

Mr. J. I. Thornycroft (Member of Council): My Lord, I beg to make a few remarks upon this subject, because I feel that the subject of loading is a very important one, and I feel also that it is very important that before a ship is designed the load that that ship will have to carry should be definitely determined. I think the case that Sir Nathaniel Barnaby has put before us is a very hard one. I think he has clearly proved that a ship is built to fulfil one set of conditions, and she is tried with another. Now, that is a hard case, and I think that is not right. In the case of the large vessels alluded to, the proportion of immersion caused by filling the bunkers has been very small, as compared to what I have to describe. So as not to give the idea that it is a personal matter with me, I wish first to draw attention to a boat which has lost speed to a great extent, by another builder, and not by any fault of the builder. Mr. White, of Cowes, built a boat which was purchased by the Admiralty. It was determined that this boat should be armed in a particular way, and be loaded to a particular degree of immersion. The boat was tried, and the speed of that boat on trial was found to be 20·6 knots per hour, with the weight of the armament on board. That boat has recently been tried since it has been fitted, and it has been so overloaded that the speed of that boat is now only 17·6 knots an hour. I think that is a great pity. The boat is a good boat, but, as it is at present loaded, it is not, in my opinion, a very useful boat. A very important feature of a torpedo-boat is that it should be fast, but 17·6 knots an hour is no longer fast. Admiral De Horsey has asked what is the use of side armour.

Admiral De Horsey: Pardon me, not Admiral De Horsey.

Captain FitzGerald: It was I that asked.

Mr. Thornycroft: I say that side armour is one of the modes of preventing a ship from upsetting or sinking, and it is not the only means. As Sir Nathaniel Barnaby has shown us, foreign navies

have found that armour now requires to be so thick that it is doubtful whether we can put armour above water without having it penetrated; and if you put armour somewhat below the water, you get the resistance of the armour plus the resistance of the water. The effect of the armour is to retain a certain volume invulnerable to water so long as it is effective in the ship, and so to retain her stability. If by putting coal above the submerged armour deck of a ship you can answer the same purpose, you probably do it in a cheaper way. I think it is quite uncertain whether or not we are right in depending on side armour. When war-ships were originally built, it was thought that we could build a house and send it afloat, with armour over the whole of the surface, to keep the shot out. But it was soon found that could not be done. The armour has got into a very small space now, and it is quite possible that it will have to be given up altogether as a means of defending anything more than the necessary passages to the submerged portions of vessels. Those are all the remarks I have to make.

Mr. W. H. White (Vice-President): My Lord, I want to explain that I do not consider myself at all a big gun, although I have purposely deferred making any remarks upon this paper until now. I can quite understand Sir Nathaniel Barnaby's feeling in writing this paper. I am, I hope, a fairly patient man myself, but I think in all probability I should have spoken before had I been in Sir Nathaniel Barnaby's position in reference to this subject. Having said that much by way of sympathy, I must add that I doubt whether this Institution is quite the place in which some of the points in this paper can best be raised. I am sure he won't be offended at my saying so much as that. I am personally responsible for the figures which are given in this paper for the completed condition of the *Impérieuse* as compared with her designed condition; and also for the probable load draught (it is only an approximate calculation as yet) of the belted cruisers. I am glad that the authorities at the Admiralty saw fit to communicate to Sir Nathaniel Barnaby, as the responsible designer of the *Impérieuse*, the figures which he has put on record here to-day. I think that is a right and proper course to pursue. When a man has had for so many years to hold the very responsible position which Sir Nathaniel Barnaby filled with such distinction, he should be informed after his retirement how his work turns out. The case of the *Impérieuse* may be summed up in this statement:—Various additions made to the ship during the progress of her construction put her deeper in the water by 11½ inches than she would have been with the weights she was designed to carry. Sir Nathaniel Barnaby states, and we know that on such a matter as that he will only state the simple fact, that every detail of the weights which the *Impérieuse* was designed to carry was submitted to and approved by the then Board of Admiralty. The question as to how much deeper in the water the ship shall be brought by putting on board five hundred tons more coal is one of the simplest calculation; and we who have to build floating structures know there is no getting away from the operation of the laws of nature in relation to floating bodies. If 500 tons more weight is put on board this ship she must sink approximately 16 inches deeper, and she will do so whether she starts from the load-line originally intended or from the line, 11½ inches deeper, at which she now floats. These excesses are all set out in the table on page 269. Of course these excesses in weight have been accompanied by various increases in fighting power. I will put the advantages first. The machinery is heavier; the ship is 1 knot faster in consequence. The armament is 160 tons heavier, and I presume that the fighting power of the ship is the better for having more powerful and more numerous guns on board. The excess on the hull is in no small degree the result of the additions to the machinery and the armament. Now that is the simple statement of fact. Of course it is not for me, as the Institution will well understand, occupying the position I now do, to make any expression whatever of personal opinion. I content myself with a statement of fact. As regards the belted cruisers, again; according to the best estimate we can make

at the present time, the triple expansion engines will drive the ships starting with 440 tons of coal further than they were originally intended to go starting with 500 tons. These ships will have in them when completed about 186 tons'—the figure is given on page 272—greater weight than was first intended. This extra weight has gone into more powerful and more economical engines, an increased complement, and heavier armaments. Leaving this statement of facts, I desire to say a few words with regard to the question of coal supply generally, and I gladly pass from what may be called a personal matter to one of general policy. I do not share the opinion of my friend Sir Nathaniel Barnaby that we can safely follow the rule followed in foreign ships, when determining the coal supply of English ships. My sympathy is more with Admiral Colomb's view, that we must endeavour—we have not done it yet—to assess our actual coal supplies, so as to fulfil our necessary requirements. Our coaling stations are known. The distances to be traversed are approximately known, and allowance can be made for any margin that may be considered desirable. If these conditions are fixed they can be met in the design. An increase in the coal supply, or in any other feature in a ship, must be accompanied by an increase in size and cost if the other features remain unaltered. It is only a question of size and cost. Naval architects and marine engineers can give speed, armament, and any other association of qualities which is within the bounds of possibility, if only the cost of production is left out of account. I do not think that those who hold the purse-strings of the Navy will be content to take that limited view of the matter. They will want to know what will this ship cost, and what are the risks she will run, when these advantages have been secured, in carrying that value into action. I must say that while I agree with Admiral Colomb's view rather than with that of Sir Nathaniel Barnaby as to policy, I regard the decision as to policy as a matter for the Board of Admiralty. Sir Nathaniel Barnaby has told us that the Boards of Admiralty of the dates when these ships were designed, approved of putting into the ships a certain weight of coal. Now that is a statement of fact, a statement within his knowledge, so that the question whether or not in the future the coal supply of English ships shall be greater or less than or equal to that of foreign ships, has nothing to do with the particular examples brought before us. With reference to the remark of Admiral Colomb that the coal supplies have been trenched upon in recent designs, and that there has been some sort of sacrifice of coal supply in order to develop other qualities, I may simply assure him of a fact which I am sure he will be glad to know, that taking into account not only the weight of coal carried, but the steaming power, the power to traverse distance, owing to the great improvements in marine engineering in recent years, our ships of recent design are far and away superior in coal endurance to the ships of which he has had personal experience. It is a small point, and a very important one, and in this tabulated statement by Sir Nathaniel Barnaby the different types of engines having different rates of economy are compared, so that the weight in the bunker capacity of a ship may be rather a misleading measure of efficiency. The recent order of the Board of Admiralty on this subject is before the world. I have nothing to say about it: but I can, perhaps, as a matter of interest, inform the Institution what I was accustomed to do when I was outside the public service and acting as my own first lord, first sea lord, director of naval ordnance, and all combined. What I always was accustomed to do was this. In designing a ship I made her capable, according to the best of my judgment, of taking on board all the coal the bunkers would hold, and to be then in an excellent fighting trim. In fixing the bunker capacity I always endeavoured to ascertain from those who were going to use the ship what limit of coal endurance they required at certain assigned speeds. Then in guaranteeing a maximum smooth water speed, which I took to be some indication of the mean speed of the ship at sea under the most favourable conditions, I said to the purchasers, Subject to your permission, this guaranteed speed shall be with the bunkers half full. It was of course a matter of indifference to the designer whether he

guaranteed one speed with the bunkers full, or another with the bunkers half full; but if there is a clear understanding in the matter nobody can complain, and certainly trying the ship with the bunkers half full gives a far better and fairer idea of her mean performance on a passage (when she starts from port full and arrives at the end of her journey nearly empty), than if the speed trials are made at the deepest load draught. The latter system of trials tells against the ship: the sailor who is on board and operating with her will say "so much the better;" but to the designer, who is desirous of doing himself as much credit as possible, that is scarcely fair. It seems to me that the real pith of this paper lies in this inquiry; which embraces also the essential difference between Sir Nathaniel Barnaby and those who have criticised the designs somewhat adversely. In what vertical position in relation to the deepest draught of the ship shall the narrow belt of armour be placed? Shall it be placed in relation to the draught of water at which the ship is intended ordinarily to float, with what is called her "normal" supply of coal on board, or shall it be placed in relation to the line at which she would float if all the coal she is capable of carrying were put into her bunkers? I think that is the key of the whole difference; and on that point my friend Sir Nathaniel Barnaby and I agreed to differ many years ago. I will only add that there is one fact deserving to be remembered in dealing with this problem. In all these ships with belt armour water ballast can be carried, over which the captain has control, and by the use of which he can regulate the position of the belt in relation to the water surface as the coal burns out. If the armour has been placed with reference to the deep load line (bunkers full), then the degree to which the ship shall be allowed to lighten is in the captain's hands. If, on the contrary, the armour-belt is placed with special reference to the ordinary load-line (normal coal), then filling up bunkers of course immerses the armour more deeply, and the captain has no power of control over its position in relation to the water surface. Other considerations necessarily come into play in settling any design, but to these it is not necessary to allude.

Captain J. D. Curtis, R.N. (Visitor): My Lord, this paper is on "Fuel Supply in Ships of War," but there has been a great deal of matter introduced beyond what one sees in the paper; but, in my humble opinion, if I am in order, I think Sir Nathaniel Barnaby in his explanation has entirely exonerated himself for the designing of these ships, because they appear to be exactly as he designed them. The power for draught of water, &c., and efficiency of the ship in a great measure depend upon her power of crossing the ocean and keeping at sea. These ships, with 450 tons of coal, would be just sufficient to escort a convoy at the rate of 10 knots an hour to New York. It is said our convoy would not be content to go at 10 knots an hour, and consequently these ships would not be able to keep up with them unless they had a larger amount of fuel. Then, again, with respect to side armour, it is a most difficult thing to penetrate a ship under water. The shot ricochet, and go into her bunkers. If that were the case, and the ship rolled, the bunker coals would be emptied into the sea, and the ship heel over on the opposite side. If war were declared with Russia—take the Pacific, for instance—the nearest coaling station from the Land's End would be the Falkland Islands, and that is distant about 6,000 miles; the fuel (that is, the 900 tons) would just take you there, and from there you would have to go to Vancouver, which is 6,000 miles more. Some of our officers, as we have heard, would do away with sails altogether, but I do not know what you would do if you did not have sufficient coal, without your masts and sails to give you power of locomotion. In the near future oil fuel will be generally used in our men-of-war, and then the power of ships will be doubled at least as to locomotion.

Sir Nathaniel Barnaby (Vice-President): My Lord and Gentlemen, you will forgive me if I take a few minutes in replying to the various things that have been said, and if I commence at a point that

was raised by my friend, Mr. White, as to the propriety of discussing the paper in the way that I have discussed it here. My feeling has always been strongly adverse to discussing questions of this kind in the public press, because it is very difficult to get the general public to understand the points in dispute. Now, my justification lies in this, that you have understood perfectly the points in dispute this morning. There is no question about it, and I do not want any other justification than that. I came here with this paper to you, because I trusted you would understand it, and because I trusted that not only would you understand it, but you would take a deep interest in the question, as I thought I ought to put it. And now I want to say a word or two upon the broad aspect of the question, that is, as to sufficiency of fuel supply ; and I would ask Admiral Colomb, and those gentlemen who have spoken in the same sense, whether it is not evident that my whole trouble, and the trouble of my colleagues, in connection with these ships has not arisen from the evident desire on our parts to give a large fuel space to the ships ? I would ask the Naval officers present if they ever heard, before they heard of the *Impérieuse*, of an armoured ship of 8,000 tons displacement, and with 900 tons of fuel ? I would ask if they ever heard of an armoured ship of 5,000 tons, like the *Undaunted* class, with 900 tons of fuel ? You know you never have. Now, Admiral Colomb has been talking to you about his flag-ship, the *Audacious*, and the coal supply. The greatest amount she could possibly carry was 500 tons. What we have got into trouble about has been that we have had a natural desire to increase the power of the ships in carrying fuel. We have done that when we have been instructed that ships are required of a certain tonnage or total weight, because that is what we are instructed. We are told that a ship is wanted of a certain tonnage and a certain size. You can understand that a limitation of that kind is what would generally lie at the basis, and does generally lie at the basis of designs, and the alternative to what we have done would have been to increase the size of the ships for the purpose of taking in twice the amount of fuel that a foreign ship takes. And in that case you must make the ship not only larger by that amount of fuel, but you must make her about two and a half times longer than the amount of fuel additional which you desire to put in. That has not been done. What has been done has been to give a large fuel supply for what we call the mean or average quantity of fuel—I call it a large fuel supply, considering what engines they have—and then to give, in addition to that, immense bunkers. I may say this: we deliberately made the bunkers much larger than we had ever talked of in the *Impérieuse* and the *Warspite*. They will hold much more than 900 tons. We never dreamed that the ships were going to be treated as they have been. If I had thought that the proper allowance of fuel would be measured by the size of the bunkers, I should certainly have reduced their size. I supposed, and I think I shall have the full sympathy of Naval officers in the matter, that if the ships were fitted with big bunkers they could at need start for long voyages with twice the amount of fuel that ships of that size were accustomed to have in Her Majesty's Navy, or that you would find in similar ships of foreign navies ; and I thought they would express some appreciation of it. Certainly the Board of Admiralty of 1881 did so. I do not think that any questions have been put that I am required to answer. I am very much obliged to you for the appreciation you have given to the points that have been raised. I desire to leave before you finally the consideration I have just dealt with, that the right way, when you have got a limited size for a ship of war, is not to reduce the armour, not to reduce the guns, not to reduce that which you want when she is fighting with her rivals, but it is to provide for that which British ships especially want, viz., the capacity to make extended passages under steam, by making the bunkers as big as ever you can. I would distinctly warn the Navy that the order which has recently been given must end in a great reduction of coal-bunker space in our ships of war. It can have no other effect.

The President: Gentlemen, in rising to return thanks to Sir Nathaniel Barnaby on your behalf for this extremely interesting paper, I am quite sure you will readily appreciate my hesitation in venturing to offer any remarks myself upon the paper, because it is unquestionable that that paper might, if handled by less skilful and discreet hands than those of the ex-Constructor of the Navy and the present Chief Constructor, have raised points and personal questions and controversies which we should all have deplored to hear. They have shown so much discretion that those points have been avoided. I cannot help making that remark, because there is always in these discussions a danger of raising personal controversies which we should all wish to see avoided. If I have a little hesitation (as you may readily understand I have) in addressing myself to the paper itself, however valuable, I have not the smallest hesitation in congratulating my friend, Sir Nathaniel Barnaby, and all of you, Gentlemen, upon the discussion that has arisen upon the paper itself. It has always appeared to me that it is absolutely due to the expenditure of time and labour which the Naval architect gives to his country that he should be brought face to face from time to time, and before an intelligent and appreciative audience, with the Naval officer who navigates the ship. Unless that opportunity is afforded to the Naval officer on the one hand, and to the Naval architect on the other, neither the one nor the other can ever come to terms. That criticism of each by the other is absolutely invaluable. I am sure they will all bear me out in that. Therefore it is that I have urged over and over again, and that I urge still, our appreciation of the presence here of Naval officers, and of the extreme value that they add to our discussions from their own personal experience of the conduct and efficiency of ships at sea. I congratulate you all upon this discussion. I have listened to it with the greatest possible interest, and I congratulate you thoroughly upon the amicable ending of what might possibly have raised a disagreeable personal controversy. I beg to return on your behalf our thanks to Sir Nathaniel Barnaby for his excellent paper.

ON THE CHANGES OF LEVEL IN THE SURFACE OF THE WATER SURROUNDING A VESSEL PRODUCED BY THE ACTION OF A PROPELLER AND BY SKIN FRICTION.

By Professor J. H. Cotterill, F.R.S., Associate Member of Council.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., in the Chair.]

On watching the action of paddles it may often be noticed that the paddle race appears to be elevated above the level of the surrounding water. It is the object of this paper to show that some such elevation must generally exist. The reasoning employed also shows that a depression is produced by skin friction, and suggests some observations on various questions at present imperfectly understood.

In two simple cases a calculation may be made with tolerable exactness, and it will be convenient to commence by considering them.

Case I.—Suppose water flowing uniformly in a canal with velocity V, the sectional area being A, and consequently the quantity $Q = VA$ in cubic feet per second. Let the breadth of the stream at the surface be b, and suppose a paddle with floats of this length, mounted on a shaft rotating in fixed bearings, at such a number of revolutions that the speed of the paddles is v. A stream flowing with velocity v will proceed from the paddles, covering the whole breadth of the canal, the surface of which is not on the same level as that of the water ahead of the paddle, but is elevated above it by a small quantity, which we can readily calculate. For, assuming such an elevation, since the race forms a nearly level uniform stream, the pressure at any depth will be greater than that at the same level in the undisturbed water by the amount y, and, neglecting the friction of the sides of the canal, the water will move along the bottom, past the paddle against the head y. Thus the velocity of the stream at the bottom of the canal is diminished from V to u where

$$V^2 - u^2 = 2\,g\,y.$$

The same reasoning applies to points at any depth below the race, and if the broken water produced by the paddle does not mingle with the stream below, the velocity u will

be the same at all depths, and the whole effect of the paddle is to increase the velocity of the water forming part of the race from V to v, and to diminish the velocity of that not forming part of the race from V to u. Let S be the sectional area of the race, then, since $A + b\,y$ is evidently the sectional area of the compound stream astern of the paddle, $A + b\,y - S$ is the area of the stream below, and therefore

$$Q = A\,V = S\,v + (A + b\,y - S)\,u,$$

which may be written

$$(A + b\,y - S)\,(V - u) = S\,(v - V) + b\,y\,.\,V;$$

combining which with the preceding equation for y gives

$$(A + b\,y - S)\,\frac{2\,g\,y}{V + u} = S\,(v - V) + b\,y\,.\,V.$$

The difference between V and u will be very small, and the product $b\,y$ will be small compared with $A - S$ except under circumstances to be noticed presently, and we therefore obtain, writing $v - V = \sigma\,V$ where σ is the "slip-ratio."

$$y = \frac{\sigma\,S\,.\,\frac{V^2}{g}}{A - S - b\,.\,\frac{V^2}{g}}$$

This result shows that the change of level was rightly assumed to be an elevation and to be small, except when the velocity of the stream approaches a certain critical value to be referred to presently.

We may now imagine the water to be at rest in the canal, and the paddle shaft to travel along the bank with velocity V: by a well-known mechanical principle the motion of the water *relatively* to the paddle remains unaltered, and we conclude that the stream of water driven astern by paddles at the surface is accompanied by a current below, moving in the opposite direction with velocity $V - u$, approximately given by the formula

$$V - u = \frac{g\,y}{V}.$$

Such a current is necessary to fill up the space originally occupied by water forming part of the race, which now occupies a smaller sectional area, in consequence of its increased velocity. It will be described in what follows as the "counter current." At the same time the paddle race is elevated by the small quantity y found by the formula given above, in which the slip-ratio is expressed, as is sometimes convenient, in terms of the speed of advance.

If the speed approach the critical value

$$V_0 = \sqrt{g\,\frac{A - S}{b}}$$

the values of y and $V - u$ are no longer small, but this is easily explained: the velocity in question being the rate of propagation of a wave of translation in a canal of section $A - S$. At this speed any disturbance tends to produce a wave, as is well known. At greater speeds a depression would be formed, not an elevation. The case where the depth is great will be considered further on, but it is more convenient first to study a modified form of the same question.

Case II.—Instead of supposing the paddle race to be a stream of small depth, covering the whole breadth of the canal, we may imagine it of the same depth but of much smaller breadth. The stream contracts in act of formation, as before, but the space left is filled with water, which flows in laterally instead of below. Otherwise the same reasoning applies, and the value of y obtained will be the mean elevation of the water level, which probably would be no longer uniform.

This case is especially interesting, from its application to the analogous case of the frictional wake of a vessel. If we imagine a board moving endways through the water, with its lower edge on the bottom of the canal and its upper edge above the surface, we have a narrow deep current which may be represented by an "equivalent uniform wake" at the rear of the board. If the board move with velocity V, and the wake glide over it with the smaller velocity v, the same reasoning which in the paddle race indicates an elevation, now shows that a depression exists, and this depression will be given by the same formula for y. It is in this way, probably, that the velocity of the water gliding over the board is prevented from diminishing indefinitely when the length of the board is increased. According to Froude's report on this subject, the diminution of friction by length of board observable up to length of 50 ft. is hardly perceptible beyond, and this may be accounted for by supposing that a slope of the surface exists, which might, perhaps, roughly be calculated by the usual hydraulic formula for the slope of a stream of velocity v coupled with the value of y obtained above.

Without attempting such a calculation, I simply remark that a slope (i) of the surface must exist, and that therefore the frictional resistance of a vessel is not merely dependent on the wetted surface, but must also include a term Δi where Δ is the displacement. This is what Rankine called the "indirect" frictional resistance, and described as due to the "heaping up" of water at the bow. It appears to me, however, that it ought to be considered as due to a depression astern. It must be remembered that a slope of 1 in. in 200 ft. is equivalent to a resistance of nearly 1 lb. per ton, and would therefore greatly add to the resistance of a vessel at moderate speeds. Rankine attempted to calculate the complete frictional resistance, including both the indirect part and also the effect of curvature, by his "augmented surface formula"; and though this formula no doubt is a short cut to the solution of a very intricate problem, I believe that it is based on sound principles, and that it is worth careful examination as a semi-empirical formula for frictional resistance only, or for total resistance at low speeds.

The constant of the formula no doubt is less than Rankine supposed it to be, because no allowance was made for the diminution of friction by length of surface; but it may be questioned whether the total neglect of indirect resistance in estimating the surface friction of a vessel does not introduce an error of equal or greater magnitude in defect. I may perhaps here be permitted to suggest that it would be very useful if the *Greyhound* experiments could be repeated with a full-sized vessel of a different type, and with a different kind of wetted surface, to see if such low co-efficients of surface friction are really permissible as are sometimes assumed for calculation purposes. When friction is neglected the principle of comparison is capable of strict demonstration, but it is only by repeated experiment that we can convince ourselves that it is applicable, notwithstanding the disturbing influence of friction, and discover the necessary corrections. It is a delicate and intricate question, which a single set of experiments is hardly sufficient to decide.

Returning now to the case of a propeller, we observe that the action of actual paddles is a combination of the two ideal cases given above. The water necessary to fill up the space left by the contraction of the race may flow in from below or laterally. Yet there can be little doubt that the counter-current is chiefly below. Theoretically its velocity may be insensible in deep water, but it appears probable that it has some sensible value near the race; if so, and if there be no broken water below the race, there will be a sensible elevation (y), greatest in the centre of the race, and increasing in shallow water, which could only be found empirically. The thrust of the paddles for a given area of race (S) will be given by the formula

$$T = w\,S\left(\frac{v\,(v - V)}{g} + y\right)$$

the 1st term being the usual formula, showing the change of momentum per second, and the 2nd expressing the effect of the elevation. The corresponding additional energy ($w\,S\,y\,v$) is employed partly in elevating the race and the water below and partly in generating the kinetic energy of the counter current. These corrections in the usual theory of paddles, though theoretically interesting, are practically unimportant, on account of their smallness, and from the imperfection of our knowledge of the facts.

Combining the cases of the frictional wake and the paddle race, we are naturally led to consider the action of a propeller on the resistance of a ship. This question is one of great importance; but it also is one of great difficulty, and in venturing to make some observations upon it I must not be understood as attempting more than a few suggestions in anticipation of a quantitative investigation, based mainly on experiment, by means of which alone real knowledge can be obtained.

In the first place, the elevation of the race may compensate, or even more than compensate, for the depression of the frictional wake, and thus we are led to conclude

that so long as a paddle works in water which has no wave disturbance, but only frictional, not only does it not necessarily augment, but it may actually diminish the resistance of the ship. The same conclusion applies with even greater force to a jet propeller discharging a jet of water through a submerged orifice either amidships or at the stern. The jet occupies less room than before entering the ship, water flows in from all sides to take its place, and in accordance with the principle explained in the case of paddles, there must be a counter current around the jet, and the surface level astern must be elevated. Thus the effect of the jet may be to reduce the resistance of the ship, and, at any rate in shallow water, to reduce it by a sensible amount.

If the paddle work among waves, no doubt the case is different. In the first place, the paddles alter in a complex way the waves in which they work, and as those waves are still in contact with the ship's side, the resistance of the ship must be directly affected. But, besides this, the counter current rising from below, as already described, must be thrown into a state of wave motion by the action of the sides of the ship, and thus absorbs energy, producing a corresponding resistance. This last is the cause of augmented resistance, which Rankine recognises in his paper read before this Institution in 1865, and it evidently is a true cause, though it must be admitted that the reasoning by which his formula is obtained is difficult, and far from satisfactory. However this be, it is certain that it is not the most important cause of augmentation, for it is only concerned with wave resistance; whereas we know that augmentation occurs at speeds such that wave resistance is of minor importance. We must, therefore, look for some other more potent cause, and in screw propellers there is such a cause, which was insisted on strongly by Froude, though Rankine seems never to have distinctly recognised it. Under certain circumstances the effect may occur in other propellers than the screw, and it will be instructive to consider a case of this kind.

Return to the paddle working in a canal, and observe that at low speeds there is no disturbance ahead at all; the resistance of a small boat moving on the surface in front of the paddle would therefore not be affected. But now suppose the paddle shaft to advance at a much greater speed than the critical speed V_o, referring to the formula for y, we see that the race would be depressed, not elevated; and the water below, instead of moving in the opposite direction, will move in the same direction as the race. Thus the whole body of water in the canal is set in motion by the paddle, the water at the bottom moving astern like the water at the surface, but with a less velocity. But if this be so, the water at the bottom cannot be imagined to be set in motion suddenly immediately below the paddle, its acceleration must commence before the paddle reaches it. Thus the whole body of water in the canal is set in motion, and its surface consequently falls for some distance ahead of the paddle. The velocity of the water is accelerated before reaching the paddle, instead of remaining undisturbed. The resistance of the small boat would then be greatly augmented, and the augmentation is due to the direct action of the propeller, and not to the action of the sides of the ship on

the disturbed water surrounding it, which is the sole cause of augmentation that Rankine appears to have admitted. And there must be a similar augmentation in every case where the nature of a propeller placed at the stern of a ship is such that it draws water through it at a greater speed than it would pass through if the propeller were not working.

The foregoing problem is of course purely ideal, but I believe its consideration will suggest to us the most important, if not the sole cause of the great augmentation of resistance which a screw propeller usually produces. If we return to the case of a low speed of advance, and imagine the paddle replaced by a screw working with a moderate slip ratio, there is nothing at first sight which distinguishes the action in the two cases; and we might suppose that, as in the paddle, there would be no disturbance immediately ahead of the propeller, so that a small boat there would offer no additional resistance. On reflection, however, it is seen that the column of water passing through the screw rotates, and that its pressure is therefore diminished at the centre; water is sucked through the screw, its velocity is accelerated for some distance ahead of the screw, and this acceleration cannot be confined to water at the depth of the centre of the screw, but must extend to the surface, the level of which will consequently be lowered. The small boat will thus have an augmented resistance. Yet these effects, at moderate slips, are probably very small, as I have attempted to show in a paper published in the *Annual of the Royal School of Naval Architecture* for 1873. There will, as in the paddle, be a counter current below to supply the room left by the contraction of the propeller race, and perhaps a corresponding elevation as before of the surface astern. But this elevation will be small, and may, conceivably, even be changed into a small depression by the broken water which may probably exist around but outside the race. Thus the thrust of the screw will nearly, but not exactly, be represented by the sternward momentum of the race.

If, now, we suppose this screw at the stern of a vessel with fine run, so that the access of water to the screw is absolutely unimpeded, there can be no difference in the working of the screw. At least, we may make this supposition as a first approximation, although, as will be seen presently, it may not be absolutely exact. But the stern of the ship will sink slightly, and her resistance will be augmented, while the speed of advance of the screw has to be taken as the difference of the speed of the vessel and the speed of the wake which follows her. This is the problem investigated experimentally by Mr. R. E. Froude, in his valuable paper read here in 1883, while the theories of Rankine and Froude represent with tolerable completeness the mechanical principles involved. These theories, no doubt, are very imperfect, considered as solutions of a mathematical problem, being not even approximate, except in extreme cases between which the case of an actual screw lies, but as far as they go they are well supported by facts. It is to be regretted, however, that experiments have not been made on screws with much narrower blades than are used in practice, in order to see if the constant in

Froude's theory is not considerably greater for an element forming part of a long, narrow blade, than for a completely isolated element. Similarly, experiments on screws with very large blades are required, to see if the thrust of a screw under any circumstances can be greater than that given by Rankine's formula.

Everyone, however, who has considered this question must have felt that when the access of water to the screw is impeded in any way, its action at once becomes essentially different, and Mr. Seaton told us last year that in vessels with a full stern the proportions and dimensions of a screw for maximum efficiency become entirely different. On following out the preceding reasoning the cause of this becomes clear. When the effort of the screw to draw more water through it than naturally passes through by the motion of the vessel, is hindered in any way, the level of the water between the screw and the stern of the ship is lowered to a much greater extent than before by the same speed of rotation of the race and the stern of the vessel sinks further, thus causing a greatly increased augmentation of resistance. Not only is this the case, but the action of the screw is altered on account of the sensible difference of level between the surfaces of the water ahead and astern of the screw. For if the depression be y, the thrust of a screw race of area S is increased by the quantity w S y, just as was the case in paddles when the race was elevated above still water. In the paddles the energy exerted by this augmentation of thrust was employed in elevating the race or generating the counter current, but here the increase of thrust corresponds to an increased turning couple which generates energy of rotation in the race, and further increases the depression. In this way the depression and speed of rotation of the race act and react on each other, so that an amount of "centrifugal action" originally small produces a sinkage of the stern and an augmentation of resistance which is relatively large, and which is greater the greater the difficulty the screw has in supplying itself with water.

The action may perhaps be increased thus:—The depression at the stern of the ship is analogous to the "negative wave of translation" considered by Scott Russell. It is well known that such a wave cannot exist alone, but is always followed by a train of waves which rapidly exhausts its energy unless maintained from some external source, and it is therefore probable that the screw in these cases generates its own system of waves, which become a part of the wave resistance of the vessel. The crest of a wave must lie immediately astern or actually above the screw, as is sometimes distinctly visible, and this possibly may once more increase the thrust, the speed of rotation of the race, and the sinkage.

If it be considered how small a slope corresponds to the total resistance of a vessel, it will not be surprising that that resistance may be augmented 50 per cent. or more by the accumulated action of the causes here described.

It thus appears that the thrust of a screw for a given real slip may be augmented as well as the resistance of the vessel, and when it is so, it is clear that the real slip

cannot be deduced from the experimental value of the thrust by Mr. R. E. Froude's method, and it is possible that a sensible augmentation may take place, even in vessels with a fine run. Further, at high speed when the wave resistance of the vessel is large it seems possible that the ordinary wave system of the vessel, apart from augmentation, may have the effect of augmenting or diminishing the thrust of the screw. So again the wave system of the screw, by interference with that of the vessel, may increase or diminish the efficiency of propulsion. In considering this question, attention has been too exclusively fixed on the action of the screw on the vessel; the reflex action of the vessel on the screw may be equally important, not only in altering the virtual speed of advance, but also in causing a difference of level in the surface of the water ahead and astern.

Again, the velocity of the water gliding over the screw blades depends only on the real speed of advance and slip, and it is a necessary consequence that when the thrust is augmented the friction of the blades is virtually diminished, so that the slip of maximum efficiency is diminished and the value of the maximum efficiency increased. Further, the effects of centrifugal action depend on the square of the slip, and therefore the augmentation due to it must be more important at large slips than at small ones. This explains why it is that large diameters and broad blades are economical in cases where the augmentation is large. And moreover, we can understand why it is that vessels with a full stern can be propelled with tolerable economy by a screw, notwithstanding the enormous augmentation it produces, for there is a compensation in diminished slip and friction. This remark also applies to the action of the screw in driving water out of the "deadwood" which Froude describes in his remarks on Rankine's paper of 1865. The general effect of this must be nearly such as I have already stated.

In the preceding paragraphs no cause has been recognised for the low pressure existing between the screw and the stern of the vessel, except the rotation of the screw race, and in a screw with many blades none other apparently could exist, for the water entering the screw in immediate contact with the propelling edge of the blades has its velocity checked, not accelerated. But the action of a blade passing through the deadwood suggests that, with the limited blade area of actual screws, the case will be different. The low pressure existing at the back of the blades will then suck water through the wide interval between the blades. And that this is the principal cause at moderate slips is shown clearly by the fact that the augmentation is found by Mr. R. E. Froude to be, on the whole, proportionally greater at small slips than large ones; whereas at small slips the effects of centrifugal action, even when increased as above described, must be relatively feeble. This leads to the conclusion that a screw with a sufficient number of blades would at small slips produce very little augmentation. The small augmentation found by Mr. R. E. Froude to exist at the very smallest slips may be due to the "turbulence" of the wake, as described by him; but it may also be

partially due to the rotation of the frictional wake of the screw blades. Another view of the cause of augmentation here considered is to regard the stern of the vessel as partially protected by the screw blades from the inflow of water in the same manner as the blades protect each other, as described in a paper read here by the author in 1879.

However produced, the low pressure existing between the stern of the ship and the screw, when the screw is imperfectly supplied with water, must have essentially the same result: that is, it must augment the thrust of the screw as well as the resistance of the ship. It is easy to imagine that the action of the screw may be simply the counterpart of the action of the vessel, so that the two effects may be nearly equal; but how far this is really the case, and how far, in a vessel with fine run, the screw can be regarded as perfectly supplied with water, are questions which must remain over for future consideration.

To sum up what has been said, it appears that the augmentation of the resistance of a vessel by the action of a propeller is of two distinct kinds. The first is due to the disturbance of the wave system of the vessel by throwing additional water into a state of wave motion or by the direct action of the race. This is probably small at low speeds when the wave resistance is small, and only becomes important at speeds at which wave resistance is the ruling element of the resistance of the vessel. It occurs in all propellers alike. The second is due to a propeller at the stern of the ship accelerating the water which supplies it *before* entering the propeller. This occurs principally in screw propellers, and is then due to suction at the back of the blades, and to the rotation of the race. In a Whitehead torpedo it is the sole cause of augmentation, because in a deeply submerged body there is no wave resistance. It consists in a lowering of the pressure in the whole mass of water lying between the screw and the vessel, thus augmenting the resistance of the vessel and the thrust of the screw. The two effects are perhaps nearly equal. It is by far the most important part of the total augmentation of resistance at low speeds, or when the supply of water to the screw is impeded. Any augmentation of thrust in the screw is not represented by sternward momentum, and the corresponding augmentation of the turning couple on the screw is employed in accelerating the rotation of the race.

In order that a propeller may be of maximum efficiency, it must be placed at the stern of the ship, in order that it may, as Froude has explained, operate on water forming part of the frictional wake; but we now find that while doing this it must draw no water through it which does not naturally flow through it by the motion of the vessel. It is probable that this condition is satisfied much more nearly by the screw turbine than by an ordinary screw, and therefore that the augmentation is much less. And this may explain how it is that Mr. Thornycroft, in his screw turbine, has been able to approach, if not to equal, the efficiency of a screw as a

propeller. Any kind of pump when used as a propeller labours under great disadvantages, because the water which supplies it is in rapid motion, and the object is to produce an increase in that velocity, which should be small to avoid loss by slip. Hence the hydraulic losses are necessarily much larger in proportion to the useful work than when the supply water is at rest relatively to the pump, as it is when the pump is employed for ordinary purposes. But if the augmentation is diminished, evidently there is a compensating advantage, and we may hope for great economy in applying it to vessels with full lines in which the augmentation is so large. At least, we may expect this to be the case in smooth water, but it must be admitted that the power of adaptation to conditions which are subject to rapid and large variations which an ordinary screw propeller possesses, is not likely to be obtained in any other way.

NOTES.

I.—Theory of the Screw Propeller.

The theory of the action of a screw in a closed pipe which it exactly fits has been considered by Professor Greenhill in some papers published in *The Engineer* commencing June, 1886. Taking a screw of large-blade area and uniform pitch, he imagines it to work in a pipe through which water is flowing in a uniform stream. The mean velocity of the stream cannot be altered by the action of the screw so long as the pipe runs full, and it is assumed that all particles move at the same speed. Hence the water suffers no change of axial velocity, but acquires an angular velocity, which is readily shown to be the same for all particles, so that the water finally rotates as a solid mass at revolutions $n\,s$, where n is the number of revolutions of the screw and s the slip ratio. The thrust of the screw is thus wholly represented by a pressure-head generated in the pipe, and the energy exerted in turning the screw-shaft is employed partly in this way, partly in shock, and partly in generating energy of rotation in the water. The distribution of pressure in the pipe, however, differs so widely from that necessary for equilibrium as to suggest that, instead of the blades having a uniform pitch at different radii, they should have a pitch diminishing from centre to circumference, according to a certain law, in order that the desired result of uniform axial motion should be obtained. It may be doubted even whether any form can be found which will satisfy the required condition at moderate slips.

In fact, assuming uniform axial motion, it is possible to calculate the pressure at any point, by considering: (1) the thrust of the corresponding portion of the screw blade, and (2) the centrifugal force due to the rotation of the screw race. The first is the pressure on a transverse section through the point in a direction parallel to the axis; we may describe it as the "axial pressure" at the point. The second is the pressure on a cylindrical surface through the point in a direction parallel to a radius; we may describe it as the "radial pressure" at the point. For equilibrium it would be necessary that these pressures should be equal, but on making the calculation it will be found that equality only exists for one particular slip-ratio. Assuming for simplicity that the screw has no boss, and further, supposing that the pressures are reckoned from the original pressure of the fluid as a zero, it will be found that the ratio of the two pressures in question is the same at all points, being simply

$$\frac{\text{Axial pressure}}{\text{Radial pressure}} = \frac{2\,(1 - s)}{s},$$

where s is the slip-ratio expressed, as usual, in terms of the speed of the screw.

Slip-ratio	·05	·1	·2	·5	·67	·8	1
Ratio of Pressures	38	18	8	2	1	·5	0

The annexed table shows the numerical results for various slip-ratios, which will be found highly instructive. At moderate slip-ratios it will be seen that centrifugal action is feeble, the pressure produced by the screw blade greatly predominating. The effect of this is that the great pressure at the circumference of the pipe would, if the supposed motion were artificially produced, at once be transmitted to the centre, the velocity of the water passing through the centre of the screw would be checked and the sectional area it occupies correspondingly increased, thus squeezing out the outer layers. The water at the circumference is thus accelerated and its pressure falls, this process going on until there is equilibrium between the pressure due to the thrust of the screw blade and that due to centrifugal action. The tabular results show clearly that at moderate slips nearly the whole thrust of the outer elements of the blade must be represented by change of momentum. At one particular slip-ratio (·67) equality exists, and the simple motion imagined by Professor Greenhill will probably closely represent the facts. At greater slip-ratios centrifugal action predominates; the motion of the water is then accelerated at the centre of the screw and retarded at the circumference. When the screw is stationary, a jet of water is projected through the centre of the screw, while a counter current exists at the circumference. There is the same difference in character in the motion produced by a screw working in open water at different slips.

A blade of uniform pitch, then, working at a moderate slip, throws back water at the circumference in a closed pipe as well as in open water, but in the closed pipe there will be a reversed action at the centre of the screw, so that the mean velocity, and consequently the total momentum, remain unaltered. The thrust of the screw, therefore, is wholly represented by a pressure head, though that head is far less than if all particles of water had the same velocity. In an ordinary screw propeller, as explained in the text, by far the greater part of its thrust is represented by sternward momentum; it is only when imperfectly supplied with water, that any large part is represented by difference of pressure.

In the same papers (June 4, 1886) a theory of the action of a screw with narrow blades is explained, from which it follows that the thrust of a screw varies as the square of the slip. This appears to be a distinctly retrograde step, and inconsistent with the result obtained for a screw with large blades. The true theory of a screw with narrow blades is given by Froude, in his paper read before this Institution in 1878, but it may be useful also to refer to a paper by Sir F. Knowles, in the "Proceedings of the Institution of Civil Engineers," vol. xxxii., with Froude's remarks in the discussion thereon. Froude's assumption that the pressure on a screw blade varies as the sine of the slip-angle, has been objected to; but it rests on a very solid basis. Objectors have hardly considered how small the slip-angle is; in practice it can hardly exceed 10°, and in general it is much less. The angle itself may be substituted for the sine with equal approximation. The constant, however, probably varies at different points of a screw blade.

On these and some other points raised by his papers, the writer is unable to share his views; but everyone interested in the subject must be indebted to Professor Greenhill for showing, by a forcible example, that difference of pressure between the supply and discharge water of a screw must have great influence on its working. It is a point which has been too little considered in reasoning about screw propellers.

II.—Paddles in Shallow Water.

When a propeller works in shallow water, the effect of the elevation of the propeller race becomes sensible. In the case of paddles, replacing y by its approximate value, the formula for the thrust given in the text becomes

$$T = w\,S\left(\frac{(v - V)}{g} + \frac{\sigma\,S}{A - S}\cdot\frac{V^2}{g}\right)$$

If T_0 be the thrust in deep water, which may be regarded as represented by change of momentum only, this may be written

$$T = T_0\left(1 + \frac{\sigma V^2}{v(v - V)} \cdot \frac{S}{A - S}\right),$$

or, since $v - V = \sigma V$,

$$T = T_0\left(1 + \frac{S}{(A - S)(1 + \sigma)}\right),$$

a formula which shows how the thrust is augmented by the elevation of the race. Since paddles draw their water almost wholly from below, S in this formula may be taken to mean the depth of the paddle race and A the depth of water. As a numerical example, suppose the slip, reckoned in the usual way on the speed of the paddles, to be 25 per cent., then $\sigma = \frac{1}{3}$. Also let the depth of water be 10 times the depth of the race, so that $A - S = 9 \cdot S$; we have then $T = \frac{13}{12} T_0$, so that the thrust is augmented about 8 per cent. The speed of the counter current is

$$V - u = \frac{\sigma S}{A - S} V = \frac{S}{A - S} \cdot (v - V),$$

which, in the particular case just given, becomes $\frac{1}{27}V$, or $\frac{1}{9}(v - V)$, that is, the water below the race is moving in the opposite direction at a velocity one-ninth that of the race.

The formulæ just given do not apply to the case of a vessel at anchor in still water, or in a current of small velocity, because in obtaining them it has been supposed that $V - u$ is small compared with V. These cases are of some theoretical interest, and will now be briefly noticed. Assume

$$\sigma = \frac{A - S}{S}, \text{ that is } v = \frac{A}{S} V.$$

For example, in the case just considered, let the speed of the paddles be ten times the speed of a current in which the vessel is anchored, then $u = -V$, and $y = 0$; in this case then there is no elevation, and the speed of the counter current below the race relatively to the vessel is equal to that of the original current, but reversed. If the speed of the paddles be still greater, there will be a small depression shown by a negative value of y. If the vessel be anchored in still water $V = 0$ the speed of the counter current and value of y are given by

$$u = -\frac{S}{A - S} \cdot v; \qquad y = -\frac{v^2}{2g} \cdot \left(\frac{S}{A - S}\right)^2.$$

It will be observed that in these extreme cases also the paddles draw water from astern by a counter current below, leaving the water ahead undisturbed. This has actually been observed to be the case.

It is probable that broken water extends to some depth below the paddles. The effect of this cannot be calculated exactly, but it must influence the results, though probably not to any great extent.

In the second ideal case considered in the text, where the race extends to the bottom of a level shallow stream, it is pre-supposed that the motion preserves the same general character. But with a paddle float of ordinary proportions this might not be the case, because there probably might not be sufficient lateral pressure to produce the necessary lateral contraction. A narrow deep float then must be supposed.

DISCUSSION.

Mr. F. P. Purvis (Member): It appears to me that this paper is rather one to be carefully pondered than readily discussed, and, when we are able to do so, I am sure we shall find very much in it that will repay the pondering. There are one or two practical points in it, though, on which I should like to say a few words, and the first is as to the experiments made by the late William Froude upon surface friction. I do not quite know whether Professor Cotterill knows that the limit of length in these experiments was 50 ft., and in extending the results obtained from planes of less than and up to 50 ft. the results were obtained not from actual experiments, but by inference from the way the resistance was increasing up to 50 ft. I do not know whether that would have any influence upon the deduction which Professor Cotterill has drawn. Mr. Froude would, if the means had been available, only too gladly have tried the effect of surface friction upon lengths greater than 50 ft., but the means did not offer themselves. As to the experiments on the *Greyhound*, I think anyone who has had to do with model experiments will bear out Professor Cotterill in wishing that something more might be done in the direction of experiments with full-sized ships, and that other boats might be tried in the same way as the *Greyhound* was tried. There are several things in connection with the comparison of models of ships on which light might be thrown if such experiments could be carried out. There is a piece of investigation of Professor Cotterill's which from practical experience I can do something to corroborate. In experimenting with paddle boats we have had the advantage of being able to obtain the contour of the wave round the side of the model, and we have also taken the contour of the wave at the corresponding speed round the side of the ship. We have done it in paddle boats more than in screw boats for two reasons: first, the speed of the paddle boat is a good deal higher in relation to length, and, second, it is more easy to get points of observation, and so for comparison have pretty carefully observed contours for both model and ship. In one case especially, what Professor Cotterill says is very well borne out. In comparing the profiles of the waves one with the other, they agree almost exactly up to the point where the waves are lost under the paddle box; when the wave emerges from the paddle box, in the actual ship reduced to a comparative scale, the wave is a good deal higher than in the model. If those who are interested in seeing the comparisons will turn to the volume of the Institution of Engineers and Shipbuilders in Scotland, for 1884 and 1885, they will find it under the head of "Paddle-steamer *Lucinda*," in a paper in the controversy on which my late universally respected and—I think the meeting will allow me to say—greatly beloved master and friend, Mr. William Denny, took part.

Professor A. G. Greenhill (Visitor): Sir, it was with much diffidence that I prepared the papers in *The Engineer* which have been alluded to by Professor Cotterill in his note. I am not myself professionally connected with naval architecture or engineering, and must consequently rank as an amateur only. Still, I think I shall have attained my chief object if I have been the cause in any way of persuading so well-known an authority as Professor Cotterill to undertake to complete the theory of the screw propeller. For I assume it will be conceded here that the theory is in some respects still incomplete, as it does not afford a definite answer to many of the questions which present themselves to a practical man. For instance, Mr. Biles mentioned yesterday in his paper on torpedo boats, that two or three propellers had to be tried before a thoroughly satisfactory result was obtained. The thrust of the propeller, according to Rankine, is derived entirely from the sternward momentum imparted to the current of water which passes through the propeller, whilst in those papers which I wrote, I attempted to obtain the thrust from the reaction of the water to the angular momentum

communicated to it by the propeller. In fact, as I have heard it stated, the propeller forms a twisted rope of the water forming the wake. In addition, the theory of Rankine necessarily requires a contraction in the stream of water passing through the propeller. This contraction, or at all events the part of it in the water available for propulsion, must take place in the very short fore and aft length of the propeller. It was to avoid the consideration of this contraction that I assumed the idea of the propeller working in a closed tube where no such contraction is possible, and where, consequently, the propeller works after the manner of the pressure turbine. When only the revolutions are altered the thrust of a propeller then varies as the slip, not as the square of the slip, as asserted by Professor Cotterill. As to the actual stream lines past and through the propeller, much careful observation is still required, as even the authorities are not yet agreed as to what actually takes place. When we look at a torpedo boat, like those described yesterday, going at about half-speed, a very small alteration of the level of the surrounding water is observable; hence the amount of sternward momentum must be exceedingly small. I hope that Professor Cotterill's valuable and interesting paper will be the means of directing experimental attention to this important subject.

Mr. E. A. Linnington (Member): Sir John Hay, we heard this afternoon of the light guns opening fire before the great guns commenced, and certainly it is an advantage to the light guns, because the ground is not cut away from under their feet before they begin to speak. I venture to express a hope that gentlemen engaged in the practical work of the profession will take part in this discussion, because I am sure that no one will be more willing to consider their remarks than Professor Cotterill; and, fortunately, although the paper is upon a very abstruse subject, it is written in ordinary language, instead of being involved in a maze of mathematical symbols, which sometimes scare the practical engineer. Permit me to draw your attention to page 291, about one-third of the distance from the top, where you will find the following sentence: "On reflection, however, it is seen that the column of water passing through the screw rotates, and that its pressure is therefore diminished at the centre; water is sucked through the screw, its velocity is accelerated for some distance ahead of the screw, and this acceleration cannot be confined to water at the depth of the centre of the screw, but must extend to the surface, the level of which will consequently be lowered." Now, in my humble opinion, there is a world of wisdom in that sentence, and in fact the matter is put so concisely that the full meaning of it may escape observation. If you will allow me, I will explain what I mean in a special case. Everyone knows that there is a large number of single-screw ships afloat in which the screw is somewhat restricted in disc, and yet is not well immersed. As a matter of fact, the draught of water will not permit so large a screw as the engineer would like to have. (Illustrating on blackboard.) This is the section of the ship a short distance in front of the screw. That is the water-line. There is the single screw. Now, apply the meaning of this sentence to a case of that sort. It need not necessarily be a "small boat," though that is the expression made use of in the sentence following. It is accepted by authorities on the screw propeller (and I gather that Professor Cotterill accepts it also) that a large quantity of the water which is sucked into the screw at the outer parts of the disc comes in from outside the disc. We see that where the screw is lightly immersed it is impossible for the water to come from outside the disc at the upper part of the disc, because the water is not there to supply the race. Then it appears to me that, in a case of this sort, where the screw is but little immersed, and where the water does not come from the outside of the disc, it must be drawn away from the run of the vessel much more than where the screw is well immersed, and there is an unusually large "augment" of the ship's resistance. I should not have ventured into the discussion of this important paper but for the fact that at the bottom of page 292 Professor Cotterill refers to a matter which I have had occasion to consider lately. Professor Cotterill

says: "It thus appears that the thrust of a screw for a given real slip may be augmented as well as the resistance of the vessel, and when it is so, it is clear that the real slip cannot be deduced from the experimental value of the thrust by Mr. R. E. Froude's method." Now, I have assumed for certain purposes, in a paper which I shall have the honour to read before you to-morrow evening, that the real slip can be deduced from Mr. Froude's model experiments; but in the paper which will be put before you the matter is not detailed to any great extent. The ships, however, are fine-lined, and the screws are twin screws; they are deeply immersed, and are well clear of the hull, so that there is a good run of water to them, and in that case I venture to think that this sentence would not quite apply. It appears that in fine-lined ships with well-immersed screws you can approximate to the real slip with the aid of Mr. Froude's experiments. Of course, the explanation of the term real slip must be considered with this statement. Permit me now to refer you to page 294: "To sum up what has been said, it appears that the augmentation of the resistance of a vessel by the action of a propeller is of two distinct kinds. The first is due to the disturbance of the wave system of the vessel by throwing additional water into a state of wave motion." It appears that, as the twin screws do not lose in efficiency from this cause, it may possibly account for some of the advantage we get with them.

Mr. W. H. White (Vice-President): It is a great matter for congratulation to the Institution that Professor Cotterill and Professor Greenhill do not agree entirely. One of the most valuable sections of the Transactions of the Institution is that which deals with this question of propulsion on the mathematical side; and I am sure that one great cause of the circulation of the Transactions in scientific circles is the fact that therein are to be found the original papers of the late Professor Rankine, the late Mr. Froude, Professor Cotterill, and Mr. Edmund Froude, who now so worthily conducts the work which his father originated for the Admiralty. I trust that Professor Greenhill, besides giving us here to-night the briefest possible explanation of his method of viewing this question, will add to our indebtedness to him by preparing for insertion in the forthcoming volume of the Transactions, a short statement of his principal methods and his principal conclusions, or else contribute a paper at a later meeting. I would simply make that suggestion, and I trust it may be carried out, for in that way we shall get what otherwise we will not have on record, a fairly complete account of a method of investigation which those who know what Professor Greenhill has done cannot but treat with the greatest respect, even though they may not agree altogether with his final opinions. Of course, in passing from the condition of these quiet student's views of what makes for economy in the propulsion of ships to the somewhat "rough and tumble" conditions which must necessarily prevail at steam trials, those of us who in some measure unite scientific knowledge with the necessity for building and propelling actual ships do realise one thing most distinctly, viz., that there is sometimes justification for practical men treating as mere refinements some of the points which the mathematical thinker puts into prominence in trying to step on from what has been done to what may be done in the path of improvement. Professor Cotterill in this paper considers various matters, some of which have attracted attention previously and have not received full explanation. There are others that he mentions now entirely for the first time, as the result of his own independent investigation, and for his work in that way the Institution is greatly indebted to him. But he would be the first to say that, while these considerations are of the greatest importance in their influence on a correct theory, they may be outweighed and counterbalanced and set aside a hundred times over by some of the conditions occurring in practice. In saying that I do not wish for a moment—and I think those who know me will believe me when I make that statement—to underrate the value of a paper such as this. I think, as a suggestion towards further observation and experiment, a paper like this, so carefully reasoned

and so sound in its mathematical views, must have a sensible influence on practice. It is no easy matter, moreover, to arrange and conduct the experiments on full-sized ships and propellers which are necessary in order to verify absolutely or to amplify theoretical investigations. The *Greyhound* experiments were made by a man who, in his capability for planning experiments, in his patient conduct of experiments, in his power as a mechanician as well as a mathematician, probably has had no rival in this century—I mean the late Mr. William Froude. But to extend those experiments to the considerable number which we have heard of to-night would be a task of immense difficulty, and I am inclined to think almost of impracticability. I should be delighted to see more experiments made on full-sized ships, but their difficulty is almost beyond expression. As regards screws, it was always our hope that we should be able to imitate in full-scale trials with screws the model experiments on screws which have been made in the Admiralty experimental works at Torquay and at Haslar. It was always our hope that these experiments might be checked and verified by large scale experiments on actual screws with surfaces in different conditions. That was part of the late Mr. Froude's original scheme, but the difficulties in the way of doing that have hitherto prevented anything really useful being accomplished. Until we can test the value of model experiments with screws by experiments on full-sized screws, I think there is wanting a trustworthy scale of comparison, such as we have between ships and models. While I value theoretical investigation, both for the resistances of ships and for the efficiency of propellers, I am perfectly convinced, from my study of the subject, and a somewhat extensive experience of steam trials, that, on going beyond precedent and reaching ever-increasing speeds, it will be necessary to depend in great measure upon the actual steam trials of ships and the analysis of the results. The truth is that even the best theory (as Professor Cotterill has said in his paper, and as Professor Greenhill has confirmed in his speech) is confessedly imperfect; and when, as a matter of fact, it is possible to vary the speed of a ship of novel type by something like 20 per cent. simply by a change in the screw, it is perfectly clear that there is a great field of inquiry still open. This must be attacked chiefly by experiment and careful observation, guided by such considerations as are set forth in the paper we have had to-night.

Mr. W. W. Beaumont (Visitor): Mr. Biles yesterday remarked that with torpedo boats his firm had had to try three different screws before they found that which was the best for the vessel, and I would suggest that the development of the screw propeller is very much in the hands of men in the position of Mr. Biles and his firm; for, when they are trying the experiments with these different screws, if they would carefully tabulate the results obtained with each of those screws at different speeds, a great deal of information of very great value might be obtained. I think that if these observations, including horse power, revolutions, and speed, were taken at a number of different speeds in each case, they might obtain a great deal of very valuable information that could not be in any way gathered from experiments taken with those screws when the ships were only running at the highest speed obtainable with them. If the speed at which each of a set of screws, with known pitch, diameter, and form, gave its greatest efficiency with a given form of vessel—*i.e.* (1) highest speed of vessel per indicated horse power, and (2) greatest distance traversed per horse power—some steps towards actual knowledge of the screw-propeller performance would be available. As Mr. Biles has already presented much valuable information to this Institution, it is not, perhaps, out of the way to suggest that, as he has these experimental things on a practical scale every now and then at his command, he might, with very little extra trouble and with very little extra expense, obtain these figures, for which the Institution would certainly thank him.

Professor J. H. Cotterill (Associate Member of Council): Gentlemen,—as regards Mr. Linning-

ton's remarks on the doubts which I feel respecting the accuracy of the method of determining the real slip of a screw by assuming that its thrust will be the same at the same slip in disturbed and undisturbed water, I need only refer him to the text of my paper, in which I have stated that the assumption is probably sufficiently accurate in vessels with a fine run, because the access of water to the screw is sensibly unimpeded. I may, however, state, in addition, that any error in estimating by comparison the efficiency of a screw in this way will be less than the error in the assumption itself, because, as explained in the paper, when the thrust of the screw is augmented, the friction is not increased in anything like the same proportion. I think nothing else has been said that requires notice, and I can only thank you for the kind manner in which you have received a paper of so abstract a character.

The Chairman: I am sure it will be the desire of the meeting to express to Professor Cotterill its thanks for the very interesting and valuable paper with which he has favoured us.

ON THE FORCES ACTING UPON THE BLADE OF A SCREW PROPELLER.

By G. A. Calvert, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., in the Chair.]

The identity of the forces acting upon the blades of a screw propeller, when propelling a vessel, with the forces acting upon a plane moving obliquely through water, was fully discussed in a paper by the late Mr. W. Froude, read before this Institution in 1878, and entitled, "On the Elementary Relation between Pitch, Slip, and Propulsive Efficiency."

That eminent writer concluded this, his last contribution to the Transactions of the Institution, with these words:—"Whatever may be the effect of the difficulties just referred to, as attaching to the extension of the solution from the action of the obliquely propelling plane to that of an actual screw, there are two assertions which may be confidently made in reference to the investigation and its results: (1) That the conclusions which have been drawn as regards the plane are in substance incontestable, so far as concerns their character and general bearings; though it is probable that quantitatively they may need some correction on the score of the incomplete exactness of the co-efficients of pressure and of friction, which have been provisionally suggested; and (2), that no theoretical treatment of the action of an actual screw can be sound, which does not incorporate and mainly rest on the principles embodied in the treatment of the problem of the plane, and, indeed, that the character of the results must, in their most essential features, be the same in both cases."

This paper was justly considered as "a new departure in the subject," yet, notwithstanding the admirable manner in which the matter was investigated, and the conviction the paper must carry, that if its assumptions were correct the conclusions drawn were of the greatest practical value, it does not appear that the mode of treatment indicated by Mr. Froude has hitherto enabled engineers to make any great advance in the *design* of screw propellers, as distinguished from the original method of "trial and error," resulting in the "survival of the fittest."

There is internal evidence in Mr. Froude's writings, that the paper referred to was

intended to be of an elementary character, dealing only with the subject in such a manner as to indicate generally the direction in which further investigation should proceed. One or two instances in support of this view may be mentioned here. The normal pressure on a plane moving obliquely through water, and also the frictional resistance of the plane, are assumed, in the 1878 paper, to increase directly as the area, and "for convenience" both normal pressure and frictional resistance are taken to increase as the square of the velocity. Now in 1871 and 1872, Mr. Froude had pointed out that it was well known that "the normal pressure was most unequally distributed over the surface of the plane, existing in great excess towards the anterior edge," * "so that a plane which is moving obliquely through water always seeks to place itself at right angles to the line of motion;" † and his experiments on surface friction, as described to the British Association in 1872, showed that the frictional resistance of a plane moving through water increased at a rate which was considerably lower than the square of the velocity, and that the co-efficient of friction differed greatly with the length of the surface. These experiments also showed that the "body resistance" (which was not taken into account in the paper of 1878) might appreciably affect the co-efficient, and as a propeller blade must necessarily have considerable thickness, thus differing from the ideal plane, this factor of body resistance could evidently not be neglected when dealing with an actual screw propeller.

"In view of the elementary nature of the conditions to be elucidated," Mr. Froude disregarded the ship's wake, and supposed the action to take place in wholly undisturbed water; with the whole surface of the propeller blade moving through the water at one inclination to its line of motion, at one "pitch-angle," and at one velocity; really each of the three latter conditions varies in the actual propeller-blade, accordingly as the portion of the blade under consideration has a greater or less radius; and the wake probably varies with every variation in the shape or speed of the vessel propelled.

The present paper is intended (1) to describe an apparatus I designed in 1885, to ascertain experimentally the forces acting on bodies having plano-convex shaped sections when moving through water either edgeways or obliquely; (2) to formulate the results of numerous experiments with the apparatus, and (3) to indicate in what way the data so obtained may be used (by a modified and extended application of Mr. Froude's method) to investigate and analyse the action of screw propellers of different proportions, or of different portions of the same propeller, and thus indicate the effect of any modification of pitch, slip, velocity, surface, shape, or thickness of blade.

Considering the pains and expense bestowed upon the economical attainment of the

* Vide Mr. Froude's remarks on Sir F. C. Knowles' paper on the Screw Propeller: Minutes of Proceedings of the Institution of Civil Engineers, vol. xxxii.

† Vide Mr. Froude's report to the Secretary of the Admiralty on Mr. Ramus' proposed ship: Parliamentary Report, No. 313, 1874.

indicated horse-power of marine engines, and knowing that a large proportion of the power so attained is irretrievably wasted or lost at the propeller, it could not fail to be interesting, even if not entirely satisfactory, to ascertain exactly how the loss takes place; this being probably the first step towards determining how the evil is to be mitigated.

The apparatus to which I have referred is shown on Fig. 1 (Plate XXI.), and may be briefly described as a carriage arranged to run along a floating tramway, and having rigidly suspended from its under side a hollow metal blade of plano-convex section, and of adjustable breadth, giving sixteen alternative sections, and breadths ranging between 12 in. and 24 in. The whole blade, although rigidly attached to the carriage, can be adjusted so that its flat face may lie at angles from 0° to about 15° with the direction of motion of the carriage, and the latter is hauled along the floating tramway, at a regular but adjustable velocity, by a line and a falling weight. The bottom or tip of the blade is immersed about 2 ft. 9 in. below the surface of the water, and a portion of the blade 3 in. in depth (being the part included between horizontal sections at 3 in. and 6 in. from the tip) is of precisely the same contour as the main portions above and below it, but separated from them by a space of about $\frac{1}{100}$ in.

The object of the experiments was to ascertain the character and magnitude of the forces acting upon this separate movable section when drawn through the water at various velocities and at different angles of inclination. The sum of all the forces consequent on such motion may be conveniently resolved into two components—one acting at right angles to the flat face of the section, the other acting parallel to the flat face; and to measure successively each of these two components, two alternative parallel motions are fitted to carry the blade section. One of these is shown on Fig. 1, being that used for measuring the normal component of the forces, and allowing of no motion relatively to the fixed blade, except in the direction of that component. The extent of this motion is limited to about $\frac{3}{8}$ in. A wire cord, attached inside to the movable section, is connected to the piston of a Richards indicator, being led over guide-pulleys carried by the fixed blade below and the carriage above. The length of the wire cord being adjustable, any required compression of the indicator-spring can be obtained by shortening the cord. If, for instance, the cord is shortened sufficiently to compress the indicator-spring equivalent to a pressure of 5 lbs., then the reaction on the movable blade section will also be 5 lbs., and its position will be at one extreme of its travel, or projecting $\frac{3}{16}$ in. beyond the face of the main blade. If, on drawing the blade through the water, the normal component of the forces acting on the movable section should exceed 5 lbs., the section will be forced back, pulling through the wire cord, and still further compressing the indicator-spring, so that any movement of the section causes a corresponding motion of the indicator-pencil, but increased fourfold. This description will equally apply to the alternative parallel motion used to measure

the component at right angles to the normal pressure, any relative motion of the blade section, in this case, being possible only in the direction of such component.

The carriage runs on four wheels, each 24 in. in circumference, which are so geared to the paper-drum of the indicator that the advance of the carriage is represented by the movement of the indicator paper to a scale of $\frac{1}{120}$th, or $\frac{1}{10}$ of an inch = 1 foot. A pencil actuated by an electro-magnet is arranged to mark the indicator paper at intervals of half a second, suitable connections being made to a pendulum on shore. The tramway is about 150 ft. in length, and a form of gearing is fitted to the carriage, by means of which the paper-drum remains at rest during the first portion of the run and until the velocity of the carriage has become fairly steady and uniform, when the drum is thrown into gear, and for the next 50 ft. of the run the pressure on the movable section of the blade is recorded on the paper. From the intervals between the dots marked by the electrical pencil the corresponding velocity in feet per second can be accurately measured.

Fig. 2 (Plate XXII.) shows the form of diagram produced, with the parallel motion arranged as shown in Fig. 1. From the diagram the normal component of the forces acting upon the section can be ascertained: *a b* being the line traced by the indicator pencil when the blade was moving through the water at a velocity of 7·66 ft. per second, as measured by the space between the dots *c d*, each space representing half a second interval; *e f* is the line drawn by the pencil with the spring uncompressed; and the distance between the lines *a b* and *e f* measures the pressure on the blade section.

As a check upon the records of the blade sections 3 in. deep, a few experiments were made with sections 6 in. deep, and they indicated pressures which were practically double those shown by the 3-in. blades.

The order in which the experiments on normal pressure were made was generally as follows:—First the blade 12 in. by 3 in. was tried, and diagrams taken with its flat face lying successively at angles of $2\frac{1}{2}°$, $5°$, $7\frac{1}{2}°$, $10°$, and $12\frac{1}{2}°$, with the line of motion of the carriage. The "motive weights" were changed, so as to give, for each angle, velocities which ranged from about 4 ft. per second to about 12 ft. per second (2·37 to 7·1 knots per hour). Then the side-pieces of the movable and fixed blades were changed, forming blades successively of 12 in., $13\frac{1}{2}$ in., 15 in., &c., up to 24 in. in breadth, each being tried at the different velocities and angles of inclination. From the indicator diagrams recorded by the blades (under the numerous combinations of breadth, velocity, and inclination) combined diagrams for each breadth and inclination were plotted, as shown in Fig. 3, where the divisions on the base represent velocities in feet per second and the lengths of the ordinates drawn perpendicular to the base line represent the normal pressures at the corresponding velocities, each ordinate being representative of one of the indicator diagrams. Fair curves being drawn through, or rather amongst, the spots so plotted, served to show the rate at which the normal pressure increased with the velocity.

Other curves were constructed in a similar manner, by using as ordinates the longitudinal or resistance components, ascertained from the indicator diagrams taken for that purpose.

If the normal pressure and the resistance varied as the square of the velocity, it would have been simply necessary to obtain information on these points at one velocity for each breadth, and at each angle of inclination. But before many groups of experiments had been combined to form curves of normal pressure and of resistance, it became evident that the law of "the square of the velocity" gave a curve which was too steep to coincide with the results of the experiments, and although the limited range of the velocities may not give a base long enough to warrant a strictly accurate estimate being made as to the normal pressures which would correspond to velocities of 50 or 60 ft. per second, there is within those limits a uniformity in the ratios of pressure to velocity which shows that the pressure varies approximately as the power 1·85 of the velocity, the resistance varying as a still lower power of the velocity.

If Mr. Froude's "law of corresponding speeds" be equally applicable to the motion of submerged bodies, the 24-in. blade section, moving at 4 ft. per second, may be considered as a model of a vessel, say, 300 ft. long, moving at a speed of about 30 knots per hour, and the 12-in. blade section, at 12 ft. per second, as representative of the same vessel at a speed of over 120 knots, so that it is not improbable that at such "corresponding speeds" the law which fairly applies to the resistance of full-sized ships at their ordinary speeds may require considerable modification when applied to the resistance and normal pressures on the submerged sections with which my experiments were made. The behaviour of torpedo boats when steaming at a high velocity, and still more strikingly the behaviour of the "Para-Ramus" model, towed by Mr. Froude at velocities corresponding to actual speeds of the full-sized vessel of over 50 knots per hour,* are independent grounds for believing that the law of the square of the velocity only holds good for a very limited range of speeds.

Another series of curves was laid down, where the measurements along the base line represented the different breadths of blade sections tried, and the lengths of the ordinates the normal pressures due to each breadth, the inclination and velocity of the blade sections being the same throughout each curve. These curves were intended to show the manner in which each successive addition to the breadth affected the normal pressure. On examination it appeared that the pressure, instead of increasing directly as the area, varied as the (breadth of the blade in the direction of its motion) m, the value of m changing with the angle of inclination, but with all the angles under consideration

* *Vide* Parliamentary Report, No. 313, 1874, where Fig. 3 (Plate XXII.) shows that the resistance of the "Para-Ramus" model, when moving at a velocity "corresponding" to about 4 ft. per second of the 12-in. blade sections, was increasing only as the 1·3 power of the speed, the trim and displacement of the model then remaining practically unchanged.

it was fractional. Here, again, the limited range of observation, extending only between breadths of 12 in. and 24 in., is scarcely sufficient to allow of a reliable statement being made as to the values of m.

This unequal distribution of pressure is, however, curiously illustrated in a paper by Herr G. Hagen,* giving the results of a series of experiments "on the position which a movable plane takes in flowing water." Planes about 13 in. long and 3 in. broad were provided with journals placed on the centre line and dividing the plane, at first, into two equal wings; one wing was successively shortened by cutting away the plane, and observations made of the angle which the plane assumed relatively to the direction of the stream in which it was immersed. When the wings were of equal length the plane ranged itself at right angles to the stream; each reduction in the length of the wing that was cut resulted in a new angle of equilibrium. For instance, when the shorter wing was one-third the length of the longer, the position assumed by the plane was at an inclination of about 7° with the line of motion of the stream. Here, as a necessity of the equilibrium, the pressure on the short or leading wing was sufficiently intense to balance the pressure on the other end, although the area was only one-fourth of the whole plane. The value of m (before referred to) for an inclination of 7° with the direction of motion must be about ·3 in order to account for the behaviour of the plane in the particular experiment just described.

Fig. 4 (Plate XXII.) shows a curve, from which the value of m can be approximately measured for any required angle of inclination. The divisions of the base line represent angles of inclination, and the length of the ordinates the values of m, measured by the vertical scale shown at the side. The crosses, amongst which the curve is drawn, are these values as deduced from Herr Hagen's recorded experiments, and agree fairly with the results of the experiments described in the present paper, up to angles of $12\frac{1}{2}°$.

The following empirical formula gives values of normal pressure P, which differ very little from the individual results of my experiments:—

$$P = p \times V^{1\cdot85} \times B^m \times D \times \sin\theta.$$

p being a co-efficient = 6.
V = the speed through the water in feet per second.
B = the breadth of the blade section, in feet, in the direction of motion.
m = the appropriate power at the angle θ, from Fig. 4.
D = the depth of the blade section in feet, measured at right angles to B.
θ = the angle of inclination, or slip angle.

It is probable that the adoption of more delicate means of measuring the normal pressure, and of trials at speeds more nearly representing the velocity of an actual propeller blade, may show that some modifications are necessary in the co-efficient, in the power of the speed, or in the values of m, but the formula as stated will be found

* Abstracted in vol. lvi., Proceedings Inst. Civil Engineers

sufficiently exact for the practical purpose to which it is applied in the concluding portion of this paper.

As regards the longitudinal component of the forces acting upon the experimental blade sections, it will, no doubt, be evident that no formula could be proposed which would be of general application. As the exact resistance of a ship cannot be ascertained from a statement of her length and draught only, nor yet from the additional knowledge of her beam and displacement (unless her form is also taken into account), so the frictional and body resistance of any section of a propeller blade can only be ascertained by direct experiment for each particular case; at any rate, until such a number of representative sections have been tried as will enable a co-efficient to be decided for each thickness and contour of section.

It now remains to be shown how the formula given above can be applied to a consideration of the action of a screw propeller.

It will be noticed that the experimental blade sections were moved through the water, for convenience, in a straight line, and in a direction parallel to the surface of the water; but there is no reason for supposing that the results would have differed if the carriage had moved vertically in deep water, or in any intermediate diagonal direction. The helical path described by a point in a propeller blade (say at a radius of 10 ft.) deviates from a straight line to the extent of less than $\frac{1}{4}$ in. in each foot of its advance, so that no serious error can arise from the assumption that a section of an actual propeller blade and its motion are very approximately represented by the experiments.

Referring now to Fig. 5 (Plate XXII.), there is shown one blade of a four-bladed propeller, assumed to be of the following proportions: Diameter 10 ft., pitch (uniform) 15 ft. Let this propeller be fitted to a vessel, which it propels at a speed of 10 knots per hour, the corresponding revolutions being 80 per minute, giving an "apparent slip" of about $15\frac{1}{2}$ per cent. To this apparent slip must be added the forward speed of the water in which the propeller is working, in order to arrive at the "real slip;" and as this forward speed, in whatever proportion it is due to the "frictional wake" or to the "wave of replacement" (if such a distinction can be made practically), is most unequal in the different portions of the wake traversed by the propeller blade in one revolution, it follows that the real slip of each individual blade is continually changing in a manner which cannot be estimated, unless the speed of every portion of the wake were known. This information could probably be obtained without much difficulty, but as it would involve towing the vessel at or about her intended speed, we may make the assumption (which will be in accordance with Mr. R. E. Froude's deductions from his experiments with model propellers) that "the wake amounts in effect to a mere uniform forward current," which we will suppose, in this case, to be moving with the ship at a speed of 1·5 knots per hour, so that the real slip will be about 28 per cent.

The blade, Fig. 5, is divided into sections, each 6 in. deep, and for illustration we

may select one of those sections, say that marked C, and endeavour to ascertain how much thrust this portion of the blade contributes to the propulsion of the vessel, and how much power it absorbs, as on these two points depends its efficiency. Taking the radius of 3 ft. 9 in. as representing, with sufficient exactness, the mean radius of section C, and laying off on the base line $a\ b$, Fig. 6 (Plate XXII.), 23·56 ft. as the corresponding circumference, and making $a\ c = 15$ ft. the pitch, the angle $a\ b\ c$ is the pitch angle at a radius of 3 ft. 9 in., $c\ d$ being the apparent slip, and $d\ e$ the assumed speed of the wake (both plotted as percentages of the pitch); the angle $c\ b\ e$ is the slip angle (about 8°) corresponding to the "angle of inclination" of the experimental blades; $e\ b$ is the development of the helical path traversed in one revolution by the section C, being a length of 25·92 ft., and as the propeller makes 80 revolutions per minute, or $1\frac{1}{3}$ revolutions per second, the velocity of the section C through the water is 34·56 ft. per second. Using the formula given on page 308 to determine the normal pressure acting on this section, the mean breadth of which is 2·2 ft., we have

$$6 \times 34{\cdot}56^{1{\cdot}85} \times 2{\cdot}2^{{\cdot}32} \times {\cdot}5 \times \sin 8^\circ = 377 \text{ lbs.}$$

which may be plotted along the line $b\ f$, at right angles to $b\ c$. Resolving this pressure into its fore and aft and transverse components, and neglecting friction, &c., we have the fore and aft thrust $f\ h = 318$ lbs., and $f\ g$ the resistance opposed to the power transmitted through the propeller shaft = 203 lbs.

But, in addition, the longitudinal component of the forces must be considered, being the frictional and body resistance of the section, which, in the absence of a formula, may be stated as being 32 lbs. for section C when moving at a velocity of 34·56 ft. per second. Laying off this (on the same scale as that used for the normal component) along $b\ i$, and resolving it in a similar manner into its fore and aft and transverse components, we may measure $b\ k = 17$ lbs., which must be subtracted from $f\ h$, leaving the net thrust $g\ k = 301$ lbs.; and this force acting through the distance moved by the ship in one minute, or 301 lbs. × 1013·3 ft. = 305003 foot lbs., or 9·24-horse power as the effective work done by section C of one blade.

Similarly the component $i\ k$ of the friction, &c., must be added to the transverse component $f\ g$, making the gross resistance = 230 lbs., which multiplied by the circumferential velocity in a minute, or 23·56 ft. × 80 revolutions × 230 lbs. = 433504 foot lbs., or 13·13-horse power, the gross work expended on section C of one blade.

$$\text{And } \frac{305003}{433504} = {\cdot}703, \text{ the relative efficiency of section C.}$$

Or the resolution of the forces may be illustrated in another manner, as follows:—The sum of the unknown forces having been experimentally resolved into the components $b\ f$ and $b\ i$, their resultant $f\ i$ represents the direction and magnitude of the sum of the forces. Again resolving $f\ i$ into its fore and aft, and transverse components, we have $i\ l$ (equal to $g\ f + i\ k$) and $f\ l$ (equal to $f\ h - b\ k$).

Dealing in the same way with the other sections, we are able to measure the thrust and resistance of each, and arranging the results of the calculations in a tabular form, it is at once seen in what proportion the indicated horse power of the engines is apportioned to the different parts of the blade. The following table gives the thrust, &c., for the sections A, B, C, &c., of the propeller blade shown on Fig. 5, working under the conditions assumed :—

Section.	Thrust, in lbs.	Effective Work H.P.	Gross Work, H.P.	Relative Efficiency.
A	321	9·85	14·18	·695
B	319	9·79	14·05	·697
C	301	9·24	13·13	·703
D	250	7·67	11·09	·692
E	198	6·08	9·00	·675
F	134	4·10	6·44	·639
G	70	2·15	4·02	·534
Total for 1 blade ...	1,593	48·88	71·91	
,, ,, 4 blades...	6,372	195·52	287·64	·679

No account has been taken in this calculation of the part of the blade lying within Section G, as its contribution to the thrust or resistance must be comparatively small, on account of its low circumferential velocity, but the resistance due to the propeller boss should be deducted from the total thrust as given, in order to arrive at the net thrust at the thrust bearing. The gross H.P. given, being that due to the propeller only, must be increased by the H.P. due to the frictional resistance of the engines and shafting varying in amount, as it will, with different types of engines. Suppose the engines driving the propeller shown at Fig. 5 to absorb 13 per cent. of the I.H.P., then, if the assumed speed of wake were correct, the total I.H.P. at 80 revolutions should be 330·6, so that a comparison of the actual I.H.P. required on trial will prove the correctness of the assumption, and thus enable the mean speed of the wake to be used with tolerable certainty in designing another propeller, of different proportions for the same vessel. It is evident that the actual mean thrust, if it could be experimentally ascertained, would give another means of checking the accuracy of the speed of wake assumed.

It will be seen that the effect of any modification in the pitch, diameter, surface, slip, revolutions, thickness, or shape of blade can be ascertained by the process, as applied to Fig. 6 (Plate XXII). One additional illustration may be given. Let another

propeller be fitted to the same vessel, having precisely the same proportions, except that Section A of each blade is removed, making the diameter 9 ft. The removal of the tips, which contributed nearly 20 per cent. of the total thrust, would leave, at 80 revolutions, and with a real slip of 28 per cent., only 5,088 lbs. thrust, which would not suffice to maintain the speed of 10 knots. Under what changed conditions, then, could the required thrust of 6,372 lbs. be obtained?

With the propeller, as with the experimental blades, an increase of normal pressure, and of its component of thrust, can be obtained either by an increased velocity (increased number of revolutions), or by increasing the angle of inclination (slip angle). But in the case of the propeller under consideration a change in one only of these conditions would not meet the case, as will be readily seen. For (1) if the slip angle remained unchanged, and the revolutions were increased to about 90, so as to obtain the required thrust of 6,372 lbs., it would follow that the ship would move at a speed of about 11 knots; but at that speed her resistance would be considerably more than 6,372 lbs. (2) If the revolutions remained unchanged, and the slip angle were increased by $1\frac{1}{2}°$ so as to give the required thrust due to the speed of 10 knots, the speed of the ship would be reduced in consequence of the increased slip to less than $9\frac{1}{2}$ knots, and her resistance at that speed would be less than 6,372 lbs.

Practically both slip and revolutions would be increased, so that the speed of 10 knots, equivalent to the thrust of 6,372 lbs., would be attained by the propeller 9 ft. diameter with very nearly 84 revolutions per minute, and a real slip of $31\frac{1}{2}$ per cent., or $19\frac{1}{2}$ per cent. apparent slip, and the distribution of thrust and efficiency would then be as shown in the following table:—

Section.	Thrust in lbs	Effective Work H.P.	Gross Work H.P.	Relative Efficiency.
A	Section A assumed to be removed.			
B	394	12·10	17·69	·683
C	368	11·30	16·49	·685
D	318	9·76	14·19	·688
E	249	7·64	11·43	·669
F	171	5·25	8·27	·635
G	93	2·85	5·12	·558
Total for 1 blade ...	1,593	48·90	73·19	—
,, ,, 4 blades...	6,372	195·60	292·76	·668

DISCUSSION.

Professor J. H. Cotterill (Associate Member of Council) : I think the experiments described in this paper are very valuable, and supply to a considerable extent the want of further information respecting the resistance of planes moving obliquely through the water at small angles of inclination. That the normal pressure on such a plane is proportional to the size of the angle may indeed be shown by theoretical reasoning to be something more than a probable assumption ; it may be regarded as being necessarily true to a considerable degree of approximation for angles not exceeding 10°, or even 15°. The case of large angles no doubt is essentially different, and I think it would be better to recognise this difference, and not attempt to include the two cases in one and the same formula especially as in screw blades the angle is always small. But Mr. Calvert not only verifies the law of the size, but goes on to show that the normal pressure varies, like the frictional resistance, as a power of the velocity, which is not exactly 2 but is somewhat less, probably because the position of the centre of pressure is altered by friction. Whatever the cause the result is important, for it shows that the ratio of the normal pressure to the frictional resistance is independent of the velocity. Now it is upon the ratio and not upon the absolute values of these quantities that the slip of maximum efficiency and the value of the maximum efficiency depend. After establishing a formula for the resistance of an oblique plane Mr. Calvert proceeds to find the thrust of a screw blade, by dividing it into spiral elements and considering each element as in the same condition as an isolated flat plate advancing through the water at the same angle of obliquity. I am afraid there is some uncertainty about this method, not on account of the curvature of the elements, which probably has little influence, but on account of their union with each other. This union, without affecting sensibly the form of the formula, either for the normal pressure or the frictional resistance, will in all probability make the constant vary from point to point of the blade. The method therefore requires experimental verification, but the results Mr. Calvert obtains by it are highly interesting, and quite in agreement with those obtained by direct experiment on model screws.

Mr. S. W. Barnaby (Member) : Mr. Chairman and Gentlemen, I do not feel able to say very much about this paper, which I think requires to be carefully read, but at the same time I may say that we must all be glad to see that actual experimental research is being carried out on model propellers by more than one person. The great difficulty in passing from the results of model experiments upon screws to the result which will be obtained in the actual propeller lies here. One can deduce exactly from the model experiments the proper sizes and proportions for a screw to drive what Mr. Froude has called a phantom ship, that is, a ship which requires the same power as a real ship to drive it, but which has no effect upon the water that it has passed through. It is possible, I say, to design a propeller for such a ship if the engines were what may be described as phantom engines, that is to say, engines which have no frictional resistance; but when you try to estimate what the friction of the engines amounts to, and what the effect of the friction of the ship amounts to—in other words, to estimate the speed of the wake—the difficulty comes in. Fortunately the one tends to balance the other, but I think it is quite impossible to get exactly at the size of the propeller from any model experiments, and, as Mr. Calvert has said, it is necessary to make assumptions as to the speed of the wake and as to the friction of the engines. As regards the effect of the wake upon the propeller, it really has more reference to the preceding paper than to the present one ; but the effect of that wake is very considerably to increase the efficiency of the propeller ; and whereas it used to be considered better to put the propeller far away from the stern, so that it would not affect the

resistance of the ship at all, we have now found considerable advantage by getting the propeller more under the ship and closer to the stern, which is made of a peculiar form in order to get more of the effect of the wake upon the propeller. There is energy in this water which has been rubbed by the ship—energy which may be utilised by the screw, and this is one direction in which improvements are likely to be met with. I think, Sir, that is all I can say about this somewhat difficult paper.

Mr. W. H. White (Vice-President): Sir John Hay and Gentlemen, before saying anything else, I desire to allude to an incident which occurred at Liverpool, and of which Mr. Calvert may have an unpleasant recollection. At the close of a meeting there, and when we were all thinking of catching a train, Mr. Calvert appeared, and gave a very brief statement—I am bound to say, in justice to myself, a very incomplete idea—of what he had been working at in these experiments. On the day following, when I had returned to London, Mr. Calvert somewhat complained, I think, of what I had said. I have now to assure him that my remarks were entirely the result of the incompleteness of his previous statement—an incompleteness made perfectly obvious by the paper read to-night. If in anything I said at that time I in any way did Mr. Calvert an injustice, I am sure he will believe that I did not mean to do it. Coming to the paper itself, I had the advantage of reading it in manuscript before it was printed, and I was greatly struck with the immense amount of labour and ingenuity in the arrangement of the apparatus, and in the detail of the results which Mr. Calvert has put before the Institution. I know of nothing, and I think I have read most that has been written on this subject—at least, most that I have been able to discover—which in some of its details approaches what has been given here. Of course there have been many experiments tried on oblique planes. Some were made by Colonel Beaufoy on thin plates. Experiments have also been made by Mr. Froude on the determination of the position of the centre of pressure in a plane moving obliquely. Mr. Calvert alludes to Mr. Hagen's experimental determination of the pressure on a plane as well as of the centre of pressure. There were also experiments, to which Mr. Calvert has not alluded, made in France by M. Joëssel, with special reference to his system of balanced rudders. These latter results were of the greatest value, and have been largely used in France in designing the large balance rudders that they have fitted to war-ships. The general character of M. Joëssel's conclusion is this:—If the normal pressure, and the moment of that pressure about the anterior edge of a plane moving at right angles to itself, are determined, then for any oblique motion the corresponding moment of the normal pressure is equal to the moment of pressure for motion at right angles to the surface of the plane, multiplied by the sine of the angle of inclination. This law of Joëssel's, associated with Mr. Froude's determination of the variation in the position of the centre pressure, with the angle of inclination, enables one to deduce very fairly the normal pressure itself for any angle of obliquity: I have done so in some of my published papers. But while I cannot express too strongly my sense of what the Institution owes to Mr. Calvert for giving us such figures and facts as these, I must add that I entirely concur with Professor Cotterill, that when one passes from a series of elements on the surface of a screw to the surface itself, there is a great step made; and I do not think that so far we can safely reason from the element, however it may have been experimented with, to the surface. It is, however, far better to know a part of the truth than to have to guess the whole; and Mr. Calvert's experiments are a distinct advance in experimental inquiry.

Mr. A. Blechynden (Member): Sir John Hay and Gentlemen, I think with the other gentlemen who have spoken that the thanks of the Institution are due to Mr. Calvert for his paper upon the interesting series of experiments which he has been at the trouble of organising and carrying out, and the data of which he has attempted to apply to determine the resistance of the screw propeller. In

spite of all that has been written upon the screw (and there has been a very great deal), there are yet many phenomena connected with its operation which are but imperfectly understood. While agreeing with much that Mr. Calvert has said, there are two points in the paper which are certainly contrary to my general experience, and to the results of some experiments which I have recently been attempting to analyse. These are, the assumptions that the screw's resistance varies with the 1·85 power of the revolutions (based, I admit, on Mr. Calvert's experiments), and the fact that the method of calculating the screw's resistance adopted would, by definitely increasing the surface, give an indefinitely large thrust. I base these objections immediately upon the results of the experiments alluded to, which were made with a series of model screws of various ratios of pitch to diameter, and of blade surface to disc area, and of various diameters from $9\frac{5}{8}$ in. to $21\frac{3}{4}$ in. Each screw was tried at about twenty-five different speeds, from about 30 to 400 revolutions per minute, and it was found that, with the same percentage of slips, the thrusts were in all cases proportional to the squares of the number of revolutions. Such small variations as there were, were well within the ordinary limit of errors of observation. In regard to the second point, though the assumption that the formula deduced from the experiments made upon planes moving in rectilineal paths may be with equal accuracy applied to plates moving in helical paths does little violence to the reason, yet, as a matter of fact, this change does actually involve another consideration, and that is, the fact that there must be a certain maximum of thrust for a screw of given pitch and diameter working with a given number of revolutions and ratio of slip. This subject has been treated by Professor Cotterill in the paper on "The Minimum Area of Blade in a Screw Propeller necessary to form a Complete Column," read before this Institution in 1879. The results obtained from a series of experiments made upon a series of sets of screws of the same diameter and pitch, but with different quantities of surface, showed that, with the same speed and slip, the thrust approached a limiting value, this limit being that which would be given by the calculation in Rankine's treatment of the subject.

Mr. G. A. Calvert (Member): Gentlemen, in replying upon this discussion, I may say that these experiments were not undertaken with the view of bringing them before this Institution, but to meet a want which I was perhaps not singular in feeling, namely, that we did not know enough about the analysis of screw-propellers. It has been the custom to treat the propeller as a whole, whereas, by the method that I have tried to indicate here, we are enabled to dissect it, and to ascertain in detail what would be the result of any modification; for example, in the shape of the blade, which perhaps has not been gone into before, although one of the principal modifications in the efficiency of the screw-propeller was due to Griffiths' alteration in shape. In reference to Mr. Blechynden's remarks about the model screws, I am not a believer in model screw experiments, because I think it is a very difficult matter to reason from a screw blade two or three inches broad up to a blade two feet or three feet broad, and to eliminate the effect due to the interference of one blade with the action of its neighbour. It is quite possible that when you have blades working as closely together as model screw blades do, you may have a very different character of result from that given by a full-sized propeller; pretty much the same difference that you would find if you put four oars in a boat, four or five inches apart, instead of being four or five feet apart. I am sorry, Sir John Hay, I am not a mathematician, and have not the pleasure that many members have of being able to follow Professor Cotterill in his—probably to them—simple way of expressing the matter, but it is beyond my powers. I do not know that I have anything to add, except to thank you for the attention with which you have listened to my paper.

The Chairman: There is a letter on this subject which perhaps the meeting will desire to hear, which the Secretary will read.

The Secretary: This is a letter which has lately been received from Mr. Stromeyer on the subject of this paper. He regrets he is unable to be present to-night, and has asked me to read it for him:—

Strawberry Hill, 30th March, 1887.

Dear Sir,—I regret that I cannot be present at the discussion of Mr. Calvert's paper on screw-propellers, but I hope that you will be able to bring under his notice the following few remarks, which I hope he will be inclined to answer:—

On page 276 of last year's Proceedings, I gave a formula, and suggested means, for determining the normal pressure for very high velocities; and as the subject is of vast importance, and as Mr. Calvert has probably still got his gear available, I hope that at some future date he will be able to supplement his present paper by further information.

Mr. Calvert has not given the details of his experimental results, and it is therefore impossible for me to compare the formula I give (viz.: $N = 3y^2 + \frac{y^2x}{4} + \frac{x^2\sqrt{y}}{3}$ where N = normal pressure per square foot of a blade 2·7 square feet area, y the normal, and x the longitudinal component of the speed in knots per hour); but I hope that, as a supplement to the paper, he will add a table of results.

I fully appreciate the difficulties Mr. Calvert has met with, and which he has so successfully overcome, and I only hope that he will be able to carry his experiments further to speeds of 60 feet per second, and thereby lay the foundation stone on which future theories for the design of rudders and screw propellers may be built up.

I am, dear Sir, yours faithfully,

G. Holmes, Esq. C. E. Stromeyer.

If Mr Calvert wishes, perhaps the meeting will not object to his replying on the letter, as it has been read after his reply.

Mr. Calvert: I am afraid, Sir, I am not able to make any reply. I remember seeing the formula of Mr. Stromeyer, but, for the reason I have just given, I could not enter into the merits of it. If there is anything I have omitted, I shall be glad to supply it, but as the result given by the formula apparently implies an equality of pressure over the whole area, it would not coincide with my own observation.

The Chairman: I am sure I shall only express the sense of the meeting when I convey to Mr. Calvert our thanks for the excellent paper which he has communicated to us this evening.

THE MACHINERY OF SMALL BOATS FOR SHIPS OF WAR.

By A. Spyer, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, March 31st, 1887; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., in the Chair.]

The object of this paper is to draw attention to the important advances which have been made of recent years in the design and construction of the machinery fitted in the small boats carried by ships of war. Prior to 1879 all these boats were fitted with high pressure machinery; since that date, however, great improvements have been introduced from all points of view, resulting in a large reduction in the weight of the machinery, with at the same time a great gain in coal economy. The three most important factors in the progress here recorded have been—(1) the application of the surface condenser; (2) the compounding of the engine; (3) the adoption of forced draught for the boilers.

The first steamboat for naval purposes was a little vessel called the *Experiment*, built and engined at H.M. Dockyard, Portsmouth, and tried in 1863, and subsequently, in 1864, these small craft made their appearance on ship-board in the form of what is now known as the steam launch. These were 42 ft. in length, and fitted with twin-screw high-pressure engines, the boiler being of the locomotive type; each screw was driven by a two-cylinder engine bolted on to the flat sides of the boiler, and the speed attained was from 6 to 6½ knots, with about 25 I.H.P.

These boats were to all intents and purposes rowing launches converted, and the speeds obtained were by comparison very satisfactory.

The exigencies of naval service, however, soon caused a rapid development in steamboats, and they shortly became differentiated into three leading classes, termed respectively launches, pinnaces, and cutters. This classification was somewhat arbitrary at first, as regards the description of steam power applied, the differences being mainly in size; but in recent times, distinctive characteristics have developed in the machinery of each of these classes, owing to the character of the boats and the nature of the service on which they are employed, and it will therefore be convenient to adopt the same classification and nomenclature.

The efforts made at the Admiralty from time to time to obtain improved types of boats and machinery have been readily responded to by many able private firms. Amongst these, Mr. John Samuel White, of Cowes, in conjunction with his engineers, Messrs. G. E. Belliss & Co., of Birmingham, has been especially successful in coping with the difficulties to be overcome ; and to the ability of these gentlemen is due, not only many improvements in detail, but the initiation of several novel types.

Dealing first with launch machinery, it will be seen from the accompanying figures that considerable progress was made in the years immediately following 1864 :—

Date.	Length of Boat.	I.H.P.	Speed. Knots.
1864	42·0	25	6·57
1866	42·0	43	7·71
1868	42·0	46	8·43

After this until 1878, the performance of the machinery of this class of boat remained nearly stationary, no important improvements having been attempted.

Two representative cases (Nos. 1 and 2) are given in the tables, showing the results of the trials and the particulars of the machinery at this date (1878). One of these boats is fitted with a locomotive boiler, and the other with a direct tube boiler of the pinnace type, which has been adopted in some cases on account of the greater facilities for cleaning, &c. ; but the engines of both were of the same twin screw high pressure description.

In 1879 an endeavour was made to improve the performance of the 42-ft. launch by increasing the power; no success resulted therefrom, however, as though the I.H.P. was nearly doubled the speed remained practically the same. The particulars of this experiment are given in the Tables, pages 328 and 329, Case 3. In the later launches for harbour service, the form of hull has been modified and length increased with a better result, the speed attained with a 52 ft. launch being 8·83 knots. This is illustrated by Example 4.

It should be remarked that the forms of these boats were not intended, or adapted for speed, and they were being rapidly replaced on board ship by the pinnaces and cutters then coming into use, the scope for the steam launch becoming gradually confined to coast and harbour service for transporting, towing, submarine mining, &c.

In a recent case, and as a consequence of the duty for which the boat was to be utilised, attention was directed to the production of an economical coal-burning engine,

and with that object in view, a launch intended for service at Plymouth and to be in constant use was provided with triple-expansion machinery.

The boiler in this case is of the ordinary cylindrical return tube type, with one circular furnace ; it is constructed entirely of steel, and loaded to 140 lbs. on the safety valves. Single screw engines are adopted, with two cranks ; there are two low pressure cylinders, the high and intermediate cylinders being placed on the top of the low pressure cylinders. This design of engine was resorted to, not as the best for triple expansion, but on account of the limited length available in the boat, which would not allow of a three-crank engine. The piston and valve rods pass through internal metallic glands to reduce the height as much as possible ; piston valves are used for the high and intermediate slides, and ordinary valves for the low pressure ; no reservoirs are provided beyond the necessary steam passages. There is a surface condenser of copper with brass tubes, and the pumps are driven off the piston rod crosshead of the after engine. These engines are illustrated in Fig. 1 (Plate XXIII.).

The particulars of this machinery and the results of the recent trials at Plymouth are given in the Tables, Example 5 ; the coal consumption was measured, and on a three hours' trial, with the steam jet in use occasionally, was found to be 2·54 lbs. per I.H.P. per hour, a result which, for machinery on so small a scale, and under these circumstances, may be considered to be a good one. The weight of the machinery is comparatively high, but this is mainly due to the type of boiler adopted.

In this instance the advantages obtainable in economy by the use of the triple-expansion engine were of sufficient importance to compensate for the somewhat additional complication and the slight extra first cost involved. The adoption of this type of machinery is, however, in a great measure dependent on the nature of the service for which the boats are to be utilised ; and as these small craft are frequently employed on detached duty away from their ships, the quantity of coal to be carried is a matter of considerable importance. Coal-boxes are provided in all boats, but the endurance is really limited by the extra quantity that can be carried in bags, and any reduction in this would allow of a corresponding increase in stores, armament, or in the number of the crew.

Shortly after the adoption of the steam launch as a portion of the boat complement of war-ships, the steam pinnace was introduced : this class of boat is of finer form than the steam launch, and has been in most cases propelled by a single screw. After a few variations in the first instance, the steam pinnace, prior to 1880, had been built in four leading sizes, the principal features of which were as follows, in representative cases :—

Length of Boat.	I.H.P.	Speed, Knots.
30·0	24	7·6
37·0	38	8·2
42·0	47	9·04
45·0	47	9·83

The machinery in all these boats is of the same type, and the leading particulars of the 37 ft. pinnace engine are given in the Tables, Example 6, and illustrated in Figs. 2 and 3 (Plates XXIV. and XXV.).

In this machinery the boiler is of the direct tube horizontal cylindrical type, entirely of steel, but with tubes usually of brass, and is intended to carry a load of 70 lbs. per square inch on the safety valves. The shells are $\frac{5}{16}$ thick, being made thicker than required for the working pressure, on account of the external corrosion found to take place at the bottom of the shells. The fire-bars are of wrought iron, and so secured that they cannot be thrown out of place by any shock or jerk. A cock is also fitted on the boiler, so that it may in case of need be filled with hot water or steam from the main boilers of the ship. A silent blast tank of copper, and water tanks of the same material, carrying about 80 gallons of water, are fitted in the air-tight casings of the boat.

The "silent blast" tank is a copper vessel into which the exhaust steam from the engines is delivered, a separate pipe leading away from this tank into the funnel, with a nozzle on its extremity to produce the funnel draught. The effect of the introduction of this tank into the path of the exhaust steam is similar to that of an air vessel on a pump; it produces a comparatively steady flow of steam into the funnel, and avoids the noise which would otherwise be produced by the jets of exhaust steam passing there direct. The mean pressure of steam in this tank when running full power is from 3 to $3\frac{1}{2}$ lbs.

The propeller is single, of gun-metal, and driven by two cylinders carried on steel columns; the covers of the cylinders and valve chests are of sheet steel pressed into shape. There are two gun-metal feed pumps driven off the end of the shaft; a small steam donkey pump, which can be used as a hand pump, is also fitted.

The total weight of the engines only is 9 cwt., and they will develop up to 40 I.H.P. at the revolutions and steam pressure usually given.

In 1879, however, in consequence of the demand for increased speed, a very important development was effected; the boiler was placed under forced draught, and

compound surface condensing engines fitted; the boat was modified to suit these conditions, and the length increased to 48 ft.

In the first instance the boiler was of the pinnace type already described, but loaded to 120 lbs. pressure, with dimensions suitably modified for the increased I.H.P.; the air pressure was obtained by a fan and separate engine in the stokehold; the engine was compound, with an internal surface condenser, and the pumps were worked off the engine shaft.

Two such boats, 48 ft. long, were tried in 1880, one being fitted with twin screws, the other with a single screw. The results were as follows:—

	Date of Trial.	Pressure of Steam.	Revolutions.	Indicated Horse Power.	Speed.	Displacement.	$\frac{D^{\frac{2}{3}} V^3}{I.H.P.}$
					Knots.	Tons.	
Single Screw	9.3.'80	119·8	304·8	103·9	12·01	13·55	94·93
Twin Screw	11.2.'80	118·5	342·6	121·2	13·39	10·73	96·43

The particulars of the twin-screw boat are given in the Tables, Example 7.

It is of interest to note here that an advantage in point of performance was shown by the twin-screw pinnace, this resulting probably from the superior propulsive efficiency of the two screws. The usual Admiralty displacement co-efficients are also given, but it should be remarked, that in these small boats the variation for displacement is probably more nearly in the direct ratio than the 2-3rd power. The twin screw arrangement is, however, in many respects not so convenient for these boats as the single screw.

It will be seen that in going from the high pressure machinery in the 37 ft. pinnace to the compound forced draught machinery in the 48 ft. boat, the weight was reduced from 1·66 cwt. to 0·9 cwt. per I.H.P., whilst the I.H.P. developed per square foot of grate surface had increased from 10½ to 20, the speed going up at the same time about 3 knots compared with the fastest high pressure boat previously in existence. A great gain in economy of fuel had been at the same time effected. In a trial made in 1880, to test the coal consumption, the following result was obtained:—

48 FT. TWIN SCREW PINNACE.

I.H.P.	Coals per I.H.P. per Hour.	Coals per Square Foot of Grate per Hour.
	Lbs.	Lbs.
123	3·19	70·3

This would be about half the coal per I.H.P. consumed in the high-pressure boats.

Latterly these fast pinnaces have been constructed in three classes, the leading features of which are as follows :—

Length of Boat.	I.H.P.	Speed. Knots.	Weight of Machinery. Cwts.
48·0	85	11¾	75
52·0	125	14½	106
56·0	150	15·0	129

The machinery, as fitted in these boats, comprises many new features introduced since the first pinnaces were tried in 1880.

The boiler, after one or two intermediate stages, has developed into what is now known as the wet firebox locomotive type ; it is constructed of steel, with tubes usually of brass, the firebox and dome being of Lowmoor iron. It is placed in the boat in a separate compartment, with a fan and engine for producing the air pressure. Single screw compound engines have been adopted, with two cylinders supported on steel columns with diagonal bracing ; the condenser is internal, of copper, with brass tubes ; the air feed and circulating pumps are driven by a separate compound engine, running about eighty revolutions per minute when the main engines are at full speed. A system of piping is provided, to enable the engines to exhaust directly overboard in the event of accident to the pumps or condenser ; and separate piping is provided so that the circulating pump may draw from the bilge and discharge directly overboard in case of a leak. A "silent blow-off" is also fitted to pass steam into the condenser from the boiler, thus avoiding the noise of steam escaping from the safety valves and the loss of fresh water. With the separate pumping engines provided the full head of steam can be maintained independently of the movements of the main engines.

The leading results now obtained in the 48 ft. and 52 ft. pinnace are given in the Tables, Cases 8 and 9. It will be seen that the improvements introduced have reduced the weight to ·79 cwt. per I.H.P., the I.H.P. developed per square foot of grate being 24·8. The general arrangement of the machinery in a 52 ft. boat is shown on Fig. 4 (Plate XXVI.).

The Herreshoff system as applied to small boats had in the meantime attracted much attention, and in 1881 two 48 ft. pinnaces, built and engined by the Herreshoff Company, were introduced and tried.

These boats were provided with single screw compound engines, and a surface condenser in the shape of a copper pipe outside the boat, and they were fitted with the coil

boiler identified with the name of Mr. Herreshoff, all the machinery being contained in one compartment, with a fan for producing the air pressure.

The Herreshoff boiler consists of a continuous coil of piping, of increasing diameter towards the lower end, and arranged in the shape of a hive, this coil being placed above the firegrate and the whole surrounded by a second coil of piping. The feed-water enters at the bottom of the external coil and ascends, passing downwards through the inner coil, from the bottom of which the mixture of steam and water is delivered into a separator, whence the steam is supplied to the engines, the water being again pumped back into the boiler. The elevation of the boiler showing the general arrangement is shown on Fig. 5 (Plate XXIV.).

A series of trials was made in 1881 in one of these boats to ascertain the performances as to speed and coal consumption; similar data being also obtained for one of the fast pinnaces with ordinary compound machinery, the boat selected for comparison being the twin screw pinnace already alluded to in Case 7.

The particulars of these trials and the dimensions of the machinery in these two boats are given in the Tables, Cases 7 and 10. Three sets of trials were made. The first on the measured mile, to test the full speed; the second, a time trial to test the coal consumption, with both boats running at the same speed; and the third, both boats running their best, with natural draught only, and 10 cwt. of coal on board.

The result of the first series showed a considerable advantage in favour of the Herreshoff boat, the speeds being respectively 15·12 and 12·6 knots; the second series showed an advantage in favour of the ordinary machinery, the coal consumption per I.H.P. being 30 per cent. greater with the Herreshoff boiler. On the third series, the Herreshoff boat, after $8\frac{24}{60}$ hours, had burnt all her coal, and had travelled over 72·5 knots, or $7\frac{1}{4}$ knots per cwt.; in the other pinnace the trial was stopped after $10\frac{8}{60}$ hours on account of darkness setting in; she had then steamed 75 knots, and still had 258 lbs. of coal left on board, being at the rate of 9·6 knots per cwt. The performance was, however, at a lower rate of speed, and the consumption per I.H.P. was greater.

No doubt a most important factor in the high results obtained as to speed in the Herreshoff boat is the light weight of the machinery, which is principally due to the boiler. In this instance there was no record of the weight, but at a somewhat later period two small pinnaces manufactured by the Herreshoff Company were tried; these boats were 33 ft. in length, and would compare most nearly with the 30 ft. Naval Service cutter for general purposes, and a trial was therefore made with one of them, in comparison with such a boat; the Herreshoff pinnace had compound machinery and a single-coil boiler, the Service cutter at that time having high pressure machinery of the usual type.

The results obtained were as follows: no indicator diagrams were, however taken on these trials:—

	Herreshoff Pinnace, 33 ft.	Service Cutter, 30 ft.
Pressure of Steam in Boiler ...	122	74
Revolutions...	305·3	457·1
Speed	8·073	7·695
Cylinders	$\frac{4\frac{1}{4}'' \text{ and } 7''}{7''}$	$\frac{(2)\ 4\frac{3}{4}''}{5''}$
Total Weight of Machinery ...	19 cwt.	33 cwt.

A trial was also made in the Herreshoff pinnace with the boiler loaded to 180 lbs. per square inch and only four persons on board, and a speed of 9·25 knots was then obtained with about 400 revolutions.

The difference in the weight of machinery is very marked, and lies almost entirely in the boilers and water contained, these weighing respectively $10\frac{3}{4}$ and 22 cwts.; in this case, however, the boiler is of the single coil type, and would be somewhat lighter proportionately than the double coil boiler fitted in the larger pinnace.

The very small quantity of water contained in these coil boilers enables steam to be raised very rapidly; with the double coil boiler on the 48 ft. pinnace mentioned the experiment was tried, and steam was raised to 60 lbs. from cold water in 5 min. 50 sec. Another result, however, of this small quantity of water is that the most careful firing is required in order to maintain a reasonably steady steam pressure; it is, moreover, found that on actual service this description of boiler wears out very rapidly.

The machinery of the third class of these small craft, the steam cutter, may fairly be said to have made advances quite comparable to those attained in either of the other two. These boats are the smallest in size, and did not appear in any number until 1874; they varied in length from 21 to 30 ft., and attained speeds of from $6\frac{1}{2}$ to 7 knots, developing 10 to 15 I.H.P. The smaller sizes were usually fitted with single cylinder, the larger with two-cylinder engines; the boilers being of the high pressure pinnace type before described.

Latterly, two-cylinder engines have been applied to all, the two leading sizes being those fitted in the 25 and 30 ft. cutters, the particulars of which are given in the Tables, Cases 11 and 12; the machinery is of the same high pressure type as that previously described for the pinnaces, except that water tanks are not fitted, as it is not possible in these small boats to carry sufficient to be of any practical service.

As a consequence, the boilers in these boats salted up very rapidly when used in sea water, and the importance of fitting a surface condenser was strongly apparent.

In 1883 a step in this direction was made by the introduction of two boats fitted with compound surface condensing machinery by Messrs. Simpson and Denison, on the "Kingdon" system. This machinery is of a special type: the engine is compound, with two cranks and four cylinders, one high and one low pressure cylinder to each crank, the high pressure cylinders being on the top of the low; the condenser is of the external type, fitted close into the keel; the boiler is cylindrical and vertical, with vertical tubes of small diameter, and is usually worked with natural draught. The pumps are driven direct, from the piston-rod crossheads.

In 1884 several boats fitted with natural draught, surface condensing, compound machinery were introduced and tried. The machinery of some of these was of the ordinary type, the grate surface of the boilers being increased, in order to compensate for the feeble natural draught, the tubes also being shortened in length, reduced in diameter, and increased in number. In most cases the outside condenser was adopted, this plan being light, efficient, and very simple, though more liable to injury from grounding. The particulars of the machinery of some of these, and the performances on the trials, are given in the Tables in Cases 13, 14, and 15. The results obtained made it clear that the compound condensing machinery with no forcing beyond that of a small steam jet in the funnel used occasionally, could be produced, even on these small dimensions, for practically the same weight as the high pressure engine with the exhaust blast; the fresh water for the boiler was saved, a great economy of fuel was effected, the firing in consequence of the large grate surface was much easier; and the noise and white cloud of steam occasioned by the exhaust blast was avoided.

To test the coal economy a series of trials was made at Portsmouth; one of the cutters tried was fitted with compound machinery of the ordinary type, and another with high pressure machinery, and the coal consumption was measured for a period of four hours, every precaution being taken to ensure an accurate record; the boats were run together, and the steam-jet was not used at all with the compound machinery, the speed at which the trial was made rendering it unnecessary. As shown in the Tables, Nos. 15 and 17, the consumptions per I.H.P. were 4·04 and 7·25 lbs. per hour respectively; that is, the high pressure engine burnt 80 per cent. more coal per I.H.P. than the compound. Further comment upon this is unnecessary.

The result obtained in this case, with the compound machinery, emphasises the difficulty that exists in very small engines, especially with the boiler attached, of obtaining a high rate of economy; a result which has since been further confirmed by the trials of several small engines.

Several modifications in detail have since been introduced with the object of obtaining an improved performance, and a case has been illustrated in the Tables, No. 16, giving the dimensions and particulars of a recent instance of compound natural-draught

machinery of the size that would be fitted in a 25-ft. cutter, and the general arrangement is shown on Fig. 6 (Plate XXVI.).

The engines are vertical compound, with two cylinders supported on steel standards, the pistons being of cast steel, with metal spring rings; a pass-valve is fitted to admit steam direct to the low pressure valve-chest, in the event of any difficulty in starting; and the rods and shafting are of steel. The surface condenser is of the external type, and consists of a taper copper pipe on either side of the keel, secured at the ends by suitable gun-metal castings; the air pump is of gun-metal, and driven off the shaft by an eccentric; and there are also two gun-metal feed-pumps, each capable of supplying the boiler with water at full power.

The boiler is of the ordinary pinnace type, but the tubes are shorter and of smaller diameter, the tube surface remaining practically the same as with the high-pressure boiler of corresponding size, but the grate area is relatively larger.

Arrangements are made to exhaust directly into the funnel, in case of accident to the condenser, and a small auxiliary steam pump is provided for feeding the boiler, pumping out the bilge, &c., this pump being also arranged to work by hand. Tanks containing about 30 gallons of fresh water are carried on the side of the boat, for making up loss to the boiler.

In comparing the weights of the compound with that of the high-pressure machinery as fitted in similar boats, it should be stated that the amount of spare gear supplied has lately been increased, and if allowance be made for this, the weights of the two are practically identical; but the I.H.P. developed is greater with the compound engine, the weights per I.H.P. being respectively 1·35 and 1·66 cwts.

In the steam cutter the closed stokehold has not yet been adopted, and this plan is for some reasons inconvenient in these very small boats; in view, however, of the comparatively low rate of combustion at present obtained, and the necessity of using a steam jet for full power, some further development in this class of machinery may, I think, be looked forward to, and this question is now receiving considerable attention.

There have been several other descriptions of machinery tried in these small vessels. Amongst others may be mentioned the Mallory system, and the Hydraulic Turbine, which latter made an appearance some little time ago in a second-class torpedo boat; and a very recent development is a tubular boiler, the invention of Mr. Thornycroft, which has been successfully tried in a similar boat.

It is, however, not possible within the limits of this paper to deal with exceptional cases, the object here being merely to indicate the course through which the machinery generally of these boats has been and is still progressing, calling attention here and there to the leading features of interest and importance. I have also, on account of

space, excluded the machinery of the torpedo boat, and dealt here only with machinery fitted in boats built until now of wood. Neither has any special reference been made to the propellers fitted in these boats, since, though anachronisms of performance due to this cause have by no means been absent, yet the questions to be considered in the analysis of the results are of a similar nature, whether occurring on a large or on a small scale, and are better met by a distinct investigation, which would enable them to be independently discussed.

In conclusion, I venture to hope that the progress indicated here in the design and construction of the machinery for these small boats may prove to be of interest, as showing that the advances made of recent times in naval marine engineering have been by no means confined to machinery on a large scale, but have simultaneously embraced even the smallest sizes.

TABLE I.

Particulars of Machinery.

	Distinguishing Number.	Length of Boat.	Description of Machinery.	Cylinders.		Propeller.			Boiler.				Ratios.		Total Weight of Machinery.
				Diameter.	Stroke.	Description.	Diameter.	Pitch.	Description.	Grate Surface.	Tube Surface.	Load on Valves.	Tube Surface / Grate Surface	Tube Area / Grate Area	
		Ft. in.			Inches.		Ft. in.	Ft. in.		Sq. ft.	Sq. f.	lbs. per sq. in			Cwts
Launches.	1	42 0	High Pressure	4 of 5½in.	6	Twin, 4 blades	2 6	3 10	Locomotive	4·65	76·0	80	16·3	6·8	77
	2	42 0	Do.	4 of 5¼in.	6	Do.	2 9	3 4½	Horizontal Direct	3·75	126·0	80	33·6	2·9	72
	3	42 0	Do.	4 of 6in.	6	Do.	2 9	3 3¼	Locomotive	5·25	121·0	104	23·0	6·6	85
	4	52 0	Do.	4 of 6in.	6	Do.	2 5½	3 4½	Do.	5·66	179·0	70	31·5	5·3	115
	5	50 0	Triple Expansion	1 of 6in., 1 of 10in., 2 of 12in.	8	Single, 3 blades	3 6	4 1⅞	Cylindrical, return tubes	10·0	180·0	140	18·0	6·7	179
Pinnaces.	6	37 0	High Pressure	2 of 6⅜in.	6	Single, 3 blades	2 9½	3 7½	Horizontal Direct	3·6	124·0	70	34·3	2·2	63
	7	48 0	Compound Surface Condensing.	2 of 7¼in., 2 of 11½in.	8	Twin, 4 blades	3 2¾	4 7⅜	Do., forced draught	5·65	200·0	120	35·4	4·3	109
	8	48 0	Do.	1 of 7⅜in., 1 of 11⅝in.	8	Single, 3 blades	2 10	3 8¾	Locomotive, wet fire-box	5·0	180·5	120	36·0	4·5	75
	9	52 0	Do.	1 of 8½in., 1 of 13in.	9	Do.	3 1	3 11¼	Do.	5·4	205·0	120	37·9	4·0	106
	10	48 0	Do. (Herreshoff)	1 of 8in., 1 of 14in.	9	Single, 4 blades	3 0	4 1	Coil	12·3	149·7	150	12·4	...	..
Cutters.	11	25 0	High Pressure ...	2 of 4in.	5	Single, 3 blades	2 3	2 6¾	Horizontal Direct	1·25	40·1	70	32·0	2·3	25
	12	30 0	Do.	2 of 4¾in.	5	Do. 4 do.	2 6½	2 2	Do.	1·77	64·5	70	36·3	2·1	33
	13	30 0	Compound (Kingdon system)	2 of 3in., 2 of 6¼in.	5⅝	Do. 3 do.	2 1⅜	3 7 3/16	Vertical	5·0	196·5	100	39·2	3·8	39
	14	30 0	Compound (ordinary system)	1 of 4½in., 1 of 7¼in.	5	Do. 3 do.	2 2¾	2 3½	Horizontal Direct	2·83	77·5	120	27·3	3·0	40
	15	25 0	Do.	1 of 4in., 1 of 8in.	5	Do. 4 do.	1 11¾	2 8	Do.	2·3	68·5	120	29·6	2·7	32
	16	28 0	Do.	1 of 4in., 1 of 7in.	5	Do. 3 do.	2 2½	2 5	Do.	2·63	48·4	120	18·4	4·8	27

Note.—The weights given above include the water in boilers and condensers and the weight of tanks, spare gear, &c., but not the water carried in the tanks.

TABLE II.

Particulars of Trials.

	Distinguishing Number.	Length of Boat.	Date of Trial.	Nature of Trial.	Pressure of Steam in Boiler.	Mean Pressure in Cylinders.	Revolutions. Mean.	I.H.P. Total.	Coals per I.H.P. per Hour.	Speed.	I.H.P. per sq. ft. of Grate.	Description of Machinery.
		Ft. in.			Lbs.	Lbs.			Lbs.	Knots.		
Launches.	1	42 0	4.6.78	Measured mile	76·5	44·7	307·0	42·0	—	7·74	9·0	High pressure machinery with locomotive boiler.
	2	42 0	7.6.79	Do.	71·1	55·17	292·3	42·3	—	8·33	11·2	High pressure machinery with horizontal boiler.
	3	42 0	30.9.79	Do.	102·0	65·18	400·2	75·0	—	8·30	14·3	Do. with locomotive boiler and increased power.
	4	52 0	23.7.85	Do.	73·1	52·20	360·9	64·6	—	8·83	11·5	Do. with locomotive boiler and increased length of boat.
	5	50 0	9.2.87	Do. & 3 hours	139·1	H. 51·1 I. 36·9 L. 10·5	283·4	70 8	2·54	9·26	7·1	Triple expansion engines.
Pinnaces.	6	37 0	9.11.85	Measured mile	77·0	62·8	311·6	37·9	—	8·27	10·4	High pressure machinery.
	8	48 0	4.11.85	Do. & 2 hours	130·0	High. 56·7 Low. 23·7	427·5	85·3	—	11·89	17·0	Compound forced draught and locomotive wet firebox boiler.
	9	52 0	24.8.86	Measured mile	120·0	47·3 25·6	485·1	134	—	15·03	24·8	Do. Do.
	7	48 0	2.8.81	Do.	125·0	— —	301·1	—	—	12·60	—	Do. Do. horizontal direct boiler.
	7	48 0	4.8.81	5½ hours	104·8	44·2 16·2	246·3	68·8	3·17	10·18	—	Do. Do.
	7	48 0	3.8.81	$10\frac{8}{60}$ hours	55·5	16·1 6·95	163·5	18·3	4·9	7·40	—	Do. Do.
	10	48 0	2.8.81	Measured mile	145·0	— —	453·0	—	—	15·12	—	Do. Do. Herreshoff boiler.
	10	48 0	4.8.81	5½ hours	93·1	53·1 12·0	333·0	68·4	4·13	10·18	—	Do. Do.
	10	48 0	3.8.81	$8\frac{24}{60}$ hours	52·3	34·2 8·02	273·2	36·7	3·88	8·63	—	Do. Do.
Cutters.	11	25 0	2.9.85	Measured mile	74·6	57·8	408·1	14·97	—	7·02	12·0	High pressure machinery with horizontal direct boiler.
	12	30 0	27.7.85	Do.	75·83	55·8	400·1	20·0	—	7·63	11·3	Do.
	15	25 0	17.12.84	Do.	120·0	H. 61·8 L. 18·1	471·8	20·1	—	6·98	8·7	Compound natural draught machinery, horizontal direct boiler.
	13	30 0	2.12.84	Do.	107·3	68·2 20·4	363·9	22·9	—	7·47	4·6	Do. Do. Kingdon boiler.
	14	30 0	13.11.84	Do.	120·8	74·8 21·8	442·0	23·3	—	7·86	8·1	Do. Do. horizontal direct boiler.
	14	30 0	1 12.84	4 hours	110·6	36·9 7·1	265·7	5·9	4·04	5·9	—	Do. Do. } Trials to test coal consumption.
	13	30 0	1.12.84	Do.	75·0	20·8	273·2	5·1	7·25		—	Do. Do. }
	16	28 0	5.7.86	Measured mile	125·0	75·2 23·4	434·3	20·2	—	7·73	7·7	Do.

DISCUSSION.

Captain C. C. P. FitzGerald (Associate): The remarks I have to offer are entirely from a practical point of view. The ship which I lately had the honour to command had three steamboats; one was on White's turnabout principle, 50 feet long, compound engines, forced draught; perhaps one of the most recent boats on the turnabout, single screw, double-balanced rudder principle. That diagram is, as near as I can see, almost an exact picture of the boat (Plate XXVI.). The other one was an ordinary 36-foot steam pinnace, with Willian's patent noiseless engines. They were of a very peculiar nature. The peculiarity was that they were supposed to be perfectly noiseless, three cylinder, single throw, the steam only acting one way on the pistons, one piston carrying the other round. I did not much like them. I could never see the inside; it was packed up in oil. The engineer told me it was not at all economical, and I cannot say it was exactly noiseless. The other was a very ordinary boat. I need not describe the ordinary pinnace, with the simple engines of the old-fashioned type; but what I want to draw attention to is the table in the lecturer's paper at page 321—the comparison between double and single screws, which I do not think is fair to the single screws. I observe that the I.H.P. of the double screw was 121, as against 103·9. The displacement of the twin screw was 10·7, as against 13·5, and the I.H.P. was also slightly in excess. I think that the displacement alone would quite sufficiently account for the extra speed, without the additional H.P. You have also to consider, in building boats for the Royal Navy, as to their general all-round use, and not exactly the result which you get on the measured mile. I am myself strongly in favour of the single screw, for various reasons, for going alongside ships and jetties and ordinary services you have to perform, because of the liability of fouling the double screws—a single screw is much less liable to foul than a double screw. Of course, we must take the risk of a breakdown, because that cannot be helped. There is one remark which I should like to make on Mr. White's turnabout boats. When we first saw them we Naval officers stood aghast. We said "that is a frightfully fragile thing;" you have only to touch the ground and the whole thing will go to smash, and that would be an end of the matter. The general idea that prevailed amongst naval officers was that they were far too fragile for real work. Well, we happened to have, the other day, a rather severe test of Mr. White's turnabout principle in the ship I commanded. They ran her on the rocks at full speed—not on purpose—it was done quite by accident, because the Admiral himself happened to be in the boat at the time. The result was something like this (I am not a very good hand at drawing pictures): the screw shaft comes out here at a slight angle (illustrating). The result of the collision on the rocks was that the whole of the screw-guard was carried away entirely, and consequently the lower pintle of the rudder was released, and the rudder stood out at an angle like that (illustrating). Both the side guards were damaged; one was carried away entirely, and the other was very much bent, although not quite broken through; the screw-shaft was put out of alignment altogether, two screw-blades were broken out of the three—there was a large piece out of one and a small piece out of the other. The boat steamed all right, and finished her business, and they did not notice any reduction of speed, or the slightest difficulty in steering. We were not going to haul her up, until somebody looked over the stern and said the whole thing was gone to pot. When we hauled her up, we found that this damage was done; but, until they came back from the cruise, they really did not know that any serious damage had happened. I simply give that as an instance of what one of these boats is capable of standing in the way of rough usage, and yet be perfectly capable of use. I saw that with my own eyes, or I would scarcely have believed it.

Mr. A. Morcom (Visitor): I am afraid, Gentlemen, that Captain FitzGerald's last remark does not reflect on us in a complimentary way, so far as our capability of designing propellers goes. I do not wish to refer to the historical part of Mr. Spyer's paper any more than is necessary, but one point ought, for the sake of my friend Mr. White to be mentioned. A reference is made to the first introduction of the outside condenser by Messrs. Simpson & Denison some few years ago. It was not our wish to keep the old high pressure engines going so long as they did. I think that was due more to the conservatism of the Naval officers than to any wishes either of the professional advisers of the Admiralty or ourselves. A boat was supplied in 1871, the invention, I believe, being due to Mr. Crichton, a retired Naval officer. It was fitted with an outside condenser of precisely the same form as the Simpson condenser. When it was first brought out, it was, of course, not fitted so perfectly as it would have been had it had the benefit of two or three years' experience in improvements. I believe the machinery was not well handled; at any rate it came to grief in the opinion of Naval officers, and although we had the boat at Portsmouth afterwards two or three times whilst I was there, and endeavoured to make her a success, she never found favour. Messrs. White & Belliss have tried to introduce that type of boat, between that time and the date of the first Simpson boat, on several occasions; and I may say we have done what we could since to knock on the head the high-pressure machinery in boats, which were not things one could take any pride in repeating, after the condensing system had been so long in vogue; but it was impossible, for the reason I have just stated. Another point I wanted to refer to was the Herreshoff boiler. I do not think it has ever had full justice done to it. I went out in a torpedo boat on the first trial made in England with the Herreshoff boiler—I forget how many years ago. We had Mr. Herreshoff, the inventor, on board with us. He was perfectly blind, but he really conducted the trial throughout, nobody else having anything to do with it except to drive under his directions. He was aided by a small piece of oily waste, which he occasionally put on the pipe to test its temperature. The trial went off without a hitch, the result of the boiler was perfect, and we had none of the trouble with the machinery we afterwards had at Portsmouth. Now it always appeared to me that at that trial, which was conducted on the Thames, with ice on the river an inch or so thick, the condenser was permitted to do some good. When we tried her at Portsmouth, the weather was very much warmer, and the condenser was one of our first failing points. The boat was never able to do her best on account of the condenser. The boiler was one that ought to have worked well, but the machinery was disgraceful, and it continually broke down. The feeding apparatus was so bad that we did not get the feed into the boiler with any regularity, and when we saw the pressure running up to 160 lb., and the gun-metal fittings turning blue, we began to look blue too, and were anxious to get out of the engine-room. These disasters were certainly due to the machinery, which was unfit to put alongside a boiler that had thoroughly good points in it. I had to conduct the trials of the two other boats referred to here, in which the Herreshoff boiler was fitted. These trials were also carried out very successfully, but the men had evidently, from their looks, come through a great deal of tribulation, in the way of accidents, to the experience necessary for the success they were able to obtain there. They seemed to me to be anticipating an explosion or that something would go adrift, and were evidently possessed of an unquiet feeling. I did not see these boats afterwards, but I understand that they have given satisfaction. The only boat in our hands was the first one, which was unable, unfortunately, on account of the condenser, to do much, and was not left long enough in active service to enable full experience to be got with her. The last I saw of her was with her nose half buried in the side of a tugboat, from which I was watching an experiment with her; and I think after that she ran very little more. The boiler, undoubtedly, if only from the result of that first experiment, carried out in the way it was, and when

the circumstances were very much better than anything we had at Portsmouth, has the elements of success in it. There is no doubt that, on account of the saving of weight, and the speed with which steam can be raised in it, some modified form of the boiler such as Messrs. Thornycroft have now developed (and after the experience they have had with the Herreshoff boiler itself, I suppose it is an improvement on it) will be possible for boats where minimum weight is of very great importance. The triple expansion engine has been referred to by Mr. Spyer, one example of it having been already fitted to a small boat. Of course, nowadays, Mr. John Samuel White and Messrs. Belliss would like to keep ahead and fit triple expansion engines wherever they appeared to be feasible, but it seems to me to be an immense jump from what we have been doing to this point. We have been content, for a long time, with very moderate rates of expansion, and I think it is within the last two years we have had high pressure engines ordered by the Admiralty, presumably because the Naval authorities considered them the best for their purpose. I think I am correct in saying that there is no compound engine on any torpedo boat, excepting one triple engine, that has a greater ratio of cylinders than 2·75 to one; I should think $2\frac{1}{2}$ to 1 is near the mark, and running with 130 lb. steam pressure. There is a great deal to be got out of the ordinary compound of this type without adopting triple expansion. You have had the ordinary compound engine running with cylinder ratios of 4 to 1, and 100 lb. steam pressure, economically, I presume, for a very long time in the merchant service, and it seems to me to be a very big jump to go to a triple expansion engine, with its inconveniences in small boats, until you get near to the maximum ratio economically possible. The triple expansion engine takes up a great deal more room fore and aft, unless you go in for a tandem engine, a thing which is top-heavy, and which very few engineers like. The triple expansion engine would, of course, be a very good thing if possible, but I think that in a short boat of 45 ft. or so, the great length taken up by a good triple expansion engine would tend, under most circumstances, to make a double compound engine with a greater ratio of expansion more valuable.

Mr. MacFarlane Gray (Member of Council): Mr. Alexander Crichton, who first made outside keel tubes for surface condensers, did not belong to the Royal Navy, as has been stated by a previous speaker. He was superintending engineer for the Cork Steamship Company, a predecessor of Mr. Calvert, who read the preceding paper. This is, therefore, one of the many contributions for which we are indebted to Ireland.

Mr. G. A. Calvert (Member): This arrangement of condenser was fitted by Mr. Crichton to two coasting steamers in 1867 and 1868. The steamers were about 230 ft. long, but, as might have been expected, the resistance caused by the pipes outside more than counterbalanced any advantage gained in the engine-room. It was afterwards fitted to the twin screw launches of Her Majesty's ships *Cambridge* and *Lord Clyde*, about 1869.

Mr. E. A. Linnington (Member): Sir John Hay and Gentlemen, Mr. Spyer in his paper has referred to the wet fire-box locomotive type of boiler, and in these boats I believe they behaved in a very satisfactory manner. There is very good reason to believe that that type of boiler, or a modification of it, will in the immediate future be found possible of application to a large number of boats and ships. It should be observed, that when locomotive boilers were tried in the Mercantile Marine, the great difficulty that was found with them was, that they salted up very rapidly. Now, at the present time, endeavours are being made, as far as possible, to supply fresh water to the boilers to make up for any waste, and probably in the future with this type of boiler there will not be the same difficulty of salting up as at the time when locomotive boilers were tried in the Mercantile Marine. I am very glad to hear Mr. Morcom say a good word for the Herreshoff type of boiler. His experience

is considerable, and anything he says on that matter must be received with respect. The advantages of the Herreshoff boiler are considerable in the way of lightness, and it is a great pity that a strenuous endeavour has not been made to overcome the objection to its use. The difficulty with the boiler is that its durability is not so satisfactory as we should like to have it. With respect to Messrs. Simpson & Denison's machinery, there is a peculiar type of boiler in connection with that machinery, and it has a feature which is rather interesting. Perhaps it is not of very much use for Service boats, but to gentlemen who use small craft for pleasure purposes it is of some interest. The boiler has a very large grate surface, and with a natural draught it will run for a long time without any stoking. In a trial I made in one of these boats some time ago, with an ordinary fire, we ran for fifty-five minutes, or roughly speaking one hour, without any stoking. At the end of that time the bars were getting bare, and I think the steam pressure had fallen from 100 lb. to 60 lb. on the square inch. We fired up, put the blast on, and soon got steam up again. Anyone who uses a boat as a pleasure craft, and has a mechanical turn of mind can do his own stoking, and he may have an opportunity of enjoying the scenery without any trouble from the boiler. Everyone must observe the full and reliable information which Mr. Spyer has given in this paper. He has given it in the most impartial manner. I am only afraid it is so full and reliable that many firms, having the information, will have the inclination to make this class of machinery, and so glut a market which is already very full.

Mr. A. Spyer (Member): Sir John Hay and Gentlemen, there is one point which I should like to allude to, and that is that there appears to be some misconception as to a statement of mine with reference to the introduction of the external surface condenser. Considering the many claims to the honour of the introduction of the external surface condenser, I refrained entirely in my paper from making any allusion as to whom the credit was due. I merely remark that so far as Her Majesty's service was concerned, it was first brought into extended notice and use in 1883. I was quite aware that it had been in existence for a long time previously to that date. As to the originator of the plan, it was a question of doubt which I did not touch upon. My friend, Mr. Morcom, made one or two remarks of very considerable importance. He states, with a great deal of reason, that apparently the assumption is, that the introduction of compound machinery in these small boats has been somewhat unduly delayed. Well, there is a great deal of truth in what he says, but he has also, at the same time, given the real explanation of it, and that is, that there was in the first instance a very strong prejudice on the part of many Naval officers against the introduction of machinery which, because it was called compound, was naturally assumed to be complicated at the same time, and that resulted really in a very considerable delay in its introduction. With reference to Mr. Morcom's objection as to the triple expansion engine, he says he thinks we are going ahead too fast. I do not know whether that is really a reasonable objection to hold. It is possible it may be a considerable step in these small boats; but, if we can hope to obtain any gain or any advantage by such introduction, I see no reason why we should not do it. I am glad also to find that the Herreshoff boiler has received to-night such ample recognition. There is no doubt that with the Herreshoff boiler some extraordinary advantages are obtainable; and in these days, with the continual pressure brought on the engineer, first of all to reduce the weight of the machinery, and then to get at the same time so much more out of it, these advantages cannot be disregarded. As I have shown in the paper, you can reduce the boiler weight by one-half at one stroke by its adoption. That is a matter of very considerable importance, if only there be any possible way of getting over the very serious practical disadvantages found to exist with that type of boiler. With reference to Captain FitzGerald's remarks, he thought I had not been quite fair to the single-screw engine mentioned on page 321. If you will refer to the table there, you will find that my statement, that there was a slight advantage in favour of the

twin-screw pinnace, was based upon the Admiralty constants, which do show an advantage in favour of the twin-screw boat; and I, at the same time, indicated that the advantage shown by these constants was really somewhat greater than it ought to have been, on account of the displacement variation, but in the one case the boat had a speed of 13·3 knots, and in the other case 12 knots. We should have anticipated, had it not been for some advantage of performance on behalf of the twin-screw boat, not a better, but a very much worse constant at the higher speed. I do not know, Gentlemen, that there are any further remarks which it is necessary to reply to, but I wish to thank you all very much for the kind manner in which you have listened to my paper.

The Chairman: Gentlemen, I suppose you will agree with me that a vote of thanks is due to Mr. Spyer for his interesting paper. Perhaps I may be allowed to say that to me it is an excessively interesting paper, as pointing out the enormous change that has been made in adding to the efficiency of the Navy in the course of the jubilee. I had the honour of serving Her Majesty's predecessor, and therefore the progress made appears very marked to me. The difficulties and hardships which were endured in rivers on the West Coast of Africa, in South America, and in Borneo, in China, and elsewhere—difficulties in landing troops, difficulties in cutting out vessels, difficulties in towing with oars, and a variety of other difficulties which devolved upon the men—are now entirely done away with. The ships are now made much more efficient, and the men are brought up to their work fresh and ready for duty. One effect of this has been to save the health of many a ship's company who were exhausted by fever and malaria, owing to the hard work which they formerly had, and which they are now saved by boat machinery. I thought it would be but fair to the lecturer and fair to the meeting, to remind them of that which an old Naval officer has seen, and of the great advantage which has accrued to the Navy in efficiency by the adoption of the machinery which has been so well explained to us by Mr. Spyer. I take it that we shall all be willing to give Mr. Spyer a vote of thanks for the paper he has read. I believe that concludes the business of the evening meeting, and I would now move that we adjourn until noon to-morrow.

COMPARATIVE EFFECTS OF BELTED AND INTERNAL PROTECTION UPON THE OTHER ELEMENTS OF DESIGN OF A CRUISER.

By J. H. Biles, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The question of the best method of protecting cruisers is a subject which has caused a considerable amount of discussion. The wide-spread interest in Naval circles which this question naturally arouses must be my excuse for venturing to bring this subject before this Institution.

The belted type of protection may be described as a belt or strip of vertical armour, forming the side of the ship in the vicinity of the water-line, and surmounted by a flat deck of about one-fifth of the thickness of the belt, forming with the belt a shield over the machinery and magazines of a ship.

The internal type of protection is usually represented by a steel deck extending from side to side of the ship, but, instead of ending with a belt of armour, it is sloped down at the side, joining the outside bottom at approximately the same point that the bottom of the armour does. The sloping part of the deck at the side of the ship is usually thicker than at the middle.

If the thickness of the internal deck be properly chosen, it is evident that the protection of the machinery and magazines from the effects of shot and shell fire may be made equal to that of the belted type. But the essential difference between these two types lies in the fact that, in the vicinity of the water-line, for a small height, the belted ship offers resistance to penetration, which would be followed by the admission of water, while the protected ship practically offers none. Assuming that it is desirable to have a belt, which some have very emphatically stated to be of vital importance, it is desirable to investigate the effect that the adoption of such a method of protection has upon the speed, cost, and other qualities of a ship, which, but for the adoption of this belt, would have had an equally good protection to her machinery and magazines in the form of an internal curved deck.

To make a definite comparison, I have selected the latest type of belted cruiser which the English Admiralty have built, viz., the *Aurora* type (Plate XXVIII.). The particulars of these vessels have been already published, but, for purposes of reference, they are given here—

	Ft.	In.
Length between perpendiculars...	300	0
Breadth, moulded	56	0
Depth, moulded at side	37	0
Draught, mean	21	0
Displacement	5,000 tons.	
	Ft.	In.
Thickness of belt armour	0	10
Do. backing	0	6
Height of belt above L.W.L.	1	6
Depth do. below L.W.L.	4	0
Length of belt, about	200	0
Thickness of deck above belt	0	2

NOTE.—Before and abaft the belt, the deck becomes an internal protective deck, and slopes down at the sides. The thickness of the sloping part is 3 in., that of the flat, 2 in.

Armament—Two 9·2 B.L. guns, one forward and one aft; ten 6-in. B.L. guns: and a number of small guns.

	Tons.
Coals, normal supply	500*
Do. full do.	1,000*
	Feet.
Metacentric height in intact condition...	2*
	Knots.
Speed	18½*
I.H.P.	8,500

Weights, approximate—

	Tons.
Provisions, stores, outfit, armament, and auxiliary machinery...	660*
Machinery and engineers' stores	830
Protection	880
Hull and conning tower	2,130
Coals...	500
	5,000

* Estimated by the author.

Starting upon the basis of these figures, I have estimated the corresponding particulars for a vessel of the protective deck type, which fulfils, as nearly as possible, the same essential conditions as the belted cruiser, except in the matter of side protection.

The comparative assumptions upon which this design is based are—

1. Length and draught of water to be the same.
2. Armament to be the same, carried at the same height above water.
3. Protection to be the same thickness on the flat as the deck of the belted cruiser. The sloped part to be at an angle of 28°, and its thickness, measured horizontally, to be the same, viz., 10 in.
4. Crew to be the same.
5. Metacentric height, in intact condition, to be the same, viz., 2 ft.
6. Speed to be the same.
7. The capacity of coal bunker above the protective-deck is the same.
8. Forms to be similar.

Upon these assumptions the principal elements of the design will be as follows :—

	Ft.	In.
Design 2.—Length between perpendiculars	300	0
Breadth, moulded	53	9
Depth	34	3
Draught, mean	21	0
Displacement	4,790 tons.	
Thickness of belt on slope	4·69 in.	
Do. flat	2·0 ,,	
Height above W.L. at centre	0 ft. 0 in.	
Depth below do. at side	6 ft.	

Note.—Before and abaft the distance that the belt extends in the belted cruiser, the decks are assumed to be of the same character and thickness in the two ships.

Armament, same as belted ship.

Coals, normal supply	500 tons.
Do. full do.	1,000 ,,
Speed	18½ knots.
I.H.P.	8,250

Weights, approximate—

	Tons.
Provisions, stores, outfit, armament, and auxiliary machinery	660
Machinery and engineers' stores	805
Protection	675
Hull and conning tower	2,050
Coals	500
	4,690
Margin of displacement = 100	4,790

Thus, on above-named assumptions, we have 100 tons more available displacement.

The debatable points of the above assumptions are Nos. 3 and 7. With respect to 3, it may be objected that no credit is given to the plating behind armour and the backing, nor to the fact that the outside armour is steel-faced; but we have to set against these the fact that a plunging shot might strike the 2-inch deck in the belted cruiser, in the part which is occupied by the sloped deck in the protective-deck cruiser, and penetrate the former when it would fail to penetrate the 4¾-inch deck of the latter; also, the coal protection in the latter is likely to be greater. Taking these facts into consideration, the fairest comparison for protection of machinery and magazines seems to me to be as in assumption 3. With reference to the bunker capacity, the assumption 7 is based on the consideration that the amount of coal which can be carried is ultimately limited, not by the space available, but by the weight which the commander considers it desirable to carry for the special purpose of the voyage he is about to undertake; and also by the consideration that the best arrangement for fighting is that which gives the greatest proportionate amount of coal above the armoured deck for a given initial metacentric height. In other words, the lower bunkers should have as little coal as possible, and, consequently, the total space occupied by coal is independent of the difference in size of the lower bunkers in the two ships.

From the foregoing list of weights it has been shown that 100 tons of displacement is to spare, in favour of the internally protected type. This weight is capable of either—

1. Adding 40 per cent. to the thickness of the flat part of the armoured deck amidships:
2. Or adding about a six-tenth of a knot to the speed of the ship:
3. Or adding one 9·2-inch gun and two 6-inch guns to the armament.

But it may, perhaps, be claimed that, in the comparison of the two types, the condition of equal draught of water should be set aside in favour of that of equal displacements. This would make available a very much larger amount of displacement for additions of the nature of the above.

Dealing only with the second one—increase of speed—and adhering to all the other assumptions, excepting the equality of draught, which is replaced by equality of displacement, we are led to the following as the elements of the design:—

	Ft.	In.
Design 3.—Length between perpendiculars	300	0
Breadth, moulded	53	0
Depth	34	3
Draught, mean	21	10
Displacement	5,000 tons.	
Thickness of belt on slope	4·69 inches.	
Do. flat	2·0 do.	

Height below W.L. at centre	0 feet 10 inches.
Do. below do. at side	6 do. 10 do.
NOTE.—Decks at ends same as before.	
Armament same as belted cruiser.	
Coals, normal supply	500 tons.
Do. full do.	1,000 ,,
Speed	20·0 knots.
I.H.P.	11,600
Approximate weights—	
Provisions, stores, outfit, armament, and auxiliary machinery ...	670
Machinery and engineers' stores	1,125
Protection	670
Hull and conning tower	2,035
Coal	500
	5,000

Thus an increase of speed of a knot and a half may be obtained in the internally protected type over the belted cruiser, on the above assumptions, at the same displacement. In the Design 3, if the protection be added to instead of the power of machinery being increased, about 44 per cent. may be added to the thickness of the whole of the deck plating.

The question of relative cost of the two types is of importance. The *Aurora's* estimated cost is for hull £215,550,* and for machinery £64,000, or £279,550. The cost of hull is made up of what may be called the armoured and the unarmoured part. The former consists of the conning tower and protecting tubes, which in all the comparisons in this paper are assumed to be the same—the armoured deck and the armour and backing on the side. I think the unarmoured part of the hull will cost £169,500; the conning tower, protecting tubes, &c., which are the same in all the cases, will cost £6,000, and the armoured deck and side will cost £40,000. The hull is £82·7 per ton, and this rate may be assumed, without great error, for the hulls of the other designs. From this basis the cost of No. 2 Design is estimated to be for hull £162,919, for conning tower, &c., £6,000, and for protective deck £10,125, or a total of £179,044. The machinery in this case is £62,060. Total cost of vessel is £241,104, against £279,500 for the belted ship. It is, therefore, evident that, as a question of first cost, the internally protected ship is £38,396 cheaper. In other words, a vessel of much greater size and increased powers of offence and defence can be built, for the same money, of the internally protected type than of the belted type. I have determined the elements of the design of a vessel of about the same first cost as the *Aurora*, upon the same data as above, and they are shown in Table A, Design 4, the other three designs being placed with this one for facility of comparison:—

* This cost is not quite accurate, but the error will not appreciably affect the comparison.

	No. 1.	No. 2.	No. 3.	No. 4.
Length	300	300	300	316
Breadth	56′ 0″	53′ 9″	53′ 0″	56′ 0″
Depth	37′ 0″	34′ 3″	34′ 3″	37′ 6″
Draught (mean)	21′ 0″	21′ 0″	21′ 10″	23′ 0″
Displacement	5,000	4,790	5,000	5,800
Thickness of Belt	10″	4·69″	4 69″	5·63″
,, Backing	6″	...	...	...
Top of Belt above or below water	above 1′ 6″	0″	below 10″	0″
Bottom ,, below water	4′ 6″	6′ 0″	6′ 10″	6′ 0″
Length of Belt	200	200	200	230
Thickness of Deck	2″	2″	2″	3″
Armament	2 9″ guns 10 6″ guns	2 9″ guns 10 6″ guns	2 9″ guns 10 6″ guns	4 9″ guns 10 6″ guns
Coals (normal)	500	500	500	750
,, (full)	1,000	1,000	1,000	1,200
Speed	18½	*18½	20·0	19½
I.H P.	8,500	*8,250	11,600	11,500
Metacentric Height in load condition ...	2·0	2 0	2·0	2·0
Weights	...	...	...	...
Provisions, Outfit, Armament, &c.	660	660	670	772
Machinery and Engineers' Stores	830	805	1,125	1,118
Protection	880	675	670	1,000
Hull and Conning Tower	2,130	2,050	2,035	2,160
Coal	500	500	500	750
Total Weights	5,000	*4,690	5,000	5,800

* If the 100 tons surplus displacement be used for machinery, speed will be 19·1 knots.

No. 4 Design—Cost of Hull	... ...	£172,000
,, Conning Tower, &c.	... ...	6,000
,, Deck Protection	... ...	15,000
,, Machinery	... ...	86,600
		£279,600

From the above, it will be seen that for about the same cost a vessel of the internally protected type can be built with 20 per cent. more protection on the slope, 50 per cent. more on the flat, two more guns of the heaviest calibre, 50 per cent. more coal, and a knot more speed. The belted ship has the advantage of the reduced length and draught, but this can be also had in the internally protected type, as in the smaller size, with the additional advantage of a greatly reduced cost.

We are now naturally led to ask the question—

1st. Is the adoption of the belt worth the extra money paid for it, with its accompanying sacrifices?

2nd. If the money is to be spent, is the belt worth the sacrifice of speed, protection, and armament which is entailed in its adoption?

The protection of the machinery and magazines from shot and shell fire is not very different, I venture to think, in the two cases. The only other question is that of protecting the buoyancy and stability by armour; but it is extremely difficult to see how a narrow strip of armour projecting, on an average, a foot and a half out of the water, and four feet under it, can be said to be likely to help to exclude water from a ship, in which the side, both above and below these points, will hardly keep a rifle bullet out. The sea is not so respectful to a Naval Architect's load-line as to make its surface conform to it at all times; and it is difficult to understand how any Naval Officer would agree to sacrifice anything in order to have the assurance that his ship's side might not have a hole in it at the average still water load-line, but was liable to have one that a horse and cart could drive through at a foot and a half above that line.

The question of the effect upon the stability of the two types of penetration of the unarmoured side, immediately above the armoured protection, may be seen by reference to Fig. 1 (Plate XXVII.) The metacentric diagram in each of the four cases discussed is given. It is assumed that the normal amount of coal is on board, that the reduction of weights of stores, &c., due to having been at sea for some time, is compensated for by water ballast. It is also assumed the compartments shown in Fig. 2 (Plate XXVII.) are damaged, and that, in order to keep the ship upright, the corresponding compartments on both sides are in communication with the sea. It is also assumed that the motion of the sea and the ship is sufficient to cause the water to enter freely the holes made in the side. In these conditions, and on these assumptions, it will be readily seen how much remaining stability there is in each case.

In Fig. 1 the metacentric heights are shown on the same assumption as above, excepting that it is assumed that the vessels have each their full quantity of coal on board.

The following Table shows clearly the amount of metacentric height, with the same amount of riddling in each case :—

	No. 1.	No. 2.	No. 3.	No. 4.
Load Condition, intact—A	2·0	2·0	2·0	2·0
Do. do. riddled—B	0·44	0·41	0·55	0·86
Deep Load Condition, intact—C	1·9	2·0	2·0	2·0
Do. do. do. riddled—D	0·37	0·48	0·8	1·05

The amount of metacentric height remaining, after riddling, is a proper measure of the protection to the stability afforded by each method of protection, and it will be seen that the percentage differences are very considerable. Another method of looking at this is, by showing approximately how many compartments may be riddled in each case before the metacentric height becomes zero. Starting from the deep load condition in each case, the Designs 1, 2, 3, and 4, will have no metacentric height when the bunkers have been flooded on each side for a length of 79 ft., 87 ft., 93 ft., and 93 ft. respectively.

I have ventured to put these facts before the Institution in the form in which they have presented themselves to me, but they do not, by any means, exhaust the question, and I hope that they may lead to the eliciting of many other facts in the discussion of this interesting question.

DISCUSSION.

Admiral A. F. R. De Horsey (Associate) : My Lord, this is so exclusively a Naval question that I make no apology for rising, although I would gladly first have heard the opinions of those who are better qualified than myself to speak upon it. I think, in the first place, it would be well to say that Mr. Biles's paper is, in my opinion, about the most important one that we have heard in this theatre. I have had the advantage of being an Associate of this Institution from its commencement, and I do not remember a paper of more national importance than this. I venture to think the subject is one that this Institution is specially qualified to form a decided opinion upon, for the guidance and assistance to a great extent of those who construct our ships at the Admiralty. It will be observed that we have three ships on the protected deck plan, to compare with one of the belt pattern. With your permission I will confine my remarks to comparing Nos. 1 and 3, Plate XXVIII. ; for this reason : No. 2

is a smaller ship than No. 1—her displacement is less—and No. 4 is a considerably larger ship with greater speed, greater armament, greater draught, and different form, therefore it is more difficult to compare No. 1 with Nos. 2 and 4, than it is with No. 3, which, if I am not mistaken, has precisely the same displacement (5,000 tons) as No. 1. Hence in No. 1 and in No. 3 we have a fair comparison of the two types—the belted ship with her armour 18 inches *above* the water-line, and the internal armour ship with no protection higher than 10 inches *below* the water-line. Let us imagine a shell striking each of those ships in the worst possible place, which I presume, in the belted ship would be immediately above the armour—one foot six inches, at least, above the water-line (because I understand we are not now considering the important question of unarmoured ends). Also I suppose that the worst place we can make the shell enter No. 3 would be at, or just below, the water-line, right in the middle of the vessel. We will further suppose that (as the author of this paper says) a hole is made that you could "drive a horse and cart through." Perhaps that is a very large hole for one shell to make, but still, let us suppose it. Now what would be the effect of this large hole made in each ship? In the case of No. 3, the water will, undoubtedly, enter the compartment struck—and almost certainly the two adjacent compartments—and will rise to the level outside, immersing the ship proportionately deeper. Succeeding projectiles entering about the water-line (unopposed by armour) will flood more compartments, and again sink the ship deeper, vitally affecting her stability. The author of this paper tells us, I think, that No. 3 will not lose her metacentric height—her final limit of safety—until the sea is admitted to 93 feet of compartments. But, what is to prevent not only large shot but small fire of every kind from entering about the water-line, and riddling compartments to the extent of 93 feet? and then what becomes of her? She will gradually sink (if she does not first upset, owing to the increased top weight). Whether she first turns bottom up, or not, is unimportant, for in any case she undoubtedly goes to the bottom. It is a matter of hydrostatic certainty that, with free communication from the sea outside, to a deck placed at a lower level than that of the sea, the water will continue to flow in until the ship is submerged. As for the so-called coal protection, it will only hasten the catastrophe; for coal, although some protection from shot, is none from water—it will not prevent the water entering where the side is pierced, but it will effectually prevent any attempt to stop the holes from the inside. Now consider the effect on No. 1 (the belted ship) with the same terrific hole—that "a horse and cart could be driven through." In this case the water does not get into the ship at all, because the armoured deck being higher than the level of the sea, the water will not run *up hill*. Riddle the ship the whole length of her armoured belt (but above it)—or even destroy the whole hull above her armour and its deck—and the ship will still be safe, and not float an inch deeper so long as her armour is unpenetrated. If the ship be rolling, some water will, of course, enter, but it will flow out again if adequate scuppers are provided. In this case the coal on deck may wash overboard, and thus improve the ship's stability and floating power, but it can do no harm. If my foregoing remarks are correct (and I think on examination of the midship section drawings of Nos. 1 and 3, and their respective designed load water-lines must confirm what I have said), the conclusion is irresistible to my mind that the belted ship, No. 1, with an armoured deck 18 inches *above* the water level, is practically unsinkable so long as she does not meet with an enemy possessing guns capable of penetrating her armour; whilst the internal armoured ship, No. 3, with her armoured deck 10 inches *below* the water-line, is vulnerable to—and may be sunk by—not only heavy guns, but light machine guns. If No. 3 engaged No. 1, No. 3 undoubtedly ought to be destroyed; and this, not necessarily because her armour is internal, but because it and the armoured deck are at too low a level. It will be poor satisfaction to No. 3—when she is sent to the bottom—to say that she had greater speed, and cost £38,000 less than her successful adversary. I am a great advocate for economy, but I can conceive no more fatal economy than to

consider the matter of cost between two ships of equal size, when it is a question of the cheaper one being destructible by the enemy, and the other *not.*

Admiral Sir John Hay (Vice-President): My Lord, I should like to add a few words to what has fallen from my gallant friend Admiral De Horsey. First of all I must compliment Mr. Biles on his paper. It is a paper of the greatest possible consequence, especially to the Navy; and, although I regret as a Naval Officer that he has left the Admiralty, I confess that, as a Scotchman, I am glad to hear he is where he is. I hope there are as good fish in the sea as ever came out of it, but they must have very good fish indeed at the Admiralty if they are as good as Mr. Biles. Mr. Biles put a question to me here: "Is the adoption of the belt worth the extra money paid for it, with its accompanying sacrifices?" To that I say, yes. But why sacrifices? He also says: "If the money is to be spent, is the money worth the sacrifice of speed, protection, and armament which is entailed in its adoption?" To that I should say, no; but I object entirely to the form of the interrogations which are put to me. That is not the shape or form in which the question raises itself in my mind. He also says, "It is difficult to understand how any Naval Officer would agree to sacrifice anything in order to have the assurance that his ship's side might not have a hole in it at the average still water load-line, but was liable to have one that "a horse and cart could drive through at one foot and a half above that line." Now, of course, nobody wishes to have a hole in their side at the still water load-line, and one will sacrifice a great many things to avoid that. My gallant friend Admiral De Horsey has shown, I think, that the still water load-line is liable to be perforated unless it is protected by armour. Now a continuous belt has this advantage, that if you are exposed to the fire of the Nordenfeldt or the Gatling—the Gatling is obsolete, but the Maxim, or one of those guns—the sawing away of 93 ft. of her side to admit the water is very easily obtained, whereas, if you have a belt, that is obviated. I am aware that Mr. Biles indicates in his paper that the ship is not always to remain perfectly steady, and, therefore, a hole which a horse and cart might go through above the belt would possibly admit the water by a very slight amount of rolling. That, of course, has to be considered, but on the other hand, many of the actions in which British ships have to be engaged, especially those in which they are opposed to land forts, are generally in perfectly smooth water, and, putting aside the question of the small guns, it would be obvious—it has been obvious—to anyone who has been engaged with forts, that on these occasions that amount of rolling in the ship is not likely to occur. The conditions under which you approach the shore and engage batteries are conditions in which ships are on an even keel, and are likely so to continue, so that the belt will, if it is not penetrated, be perfect protection, whereas, as has been shown by Admiral De Horsey, the ship which has not that protection may be penetrated at the water-line, and whether the water is smooth or otherwise, down you go. Therefore, both large guns and small guns are strong arguments to me in favour of the necessity of having at the water-line, however narrow it may be, a belt as impenetrable as the shipwright can make it, and as the ship can carry. But I refuse also to be fettered by the proposition which Mr. Biles puts before us. I do not think when you are building a man-of-war to protect your commerce, and to enable your men on board her to fight as long as she will float, that you are to question either the element of size or the element of cost. You are to choose your tool for the purpose. I want to give you an instance of that, because we have not got the tools. I hope we are always to be friendly with Italy, but if Italy and France were combined, the conundrum I should like to put before this meeting is this:—I see Sir Nathaniel Barnaby here, and I hope he will answer it—if the five Italian ships, the *Italia*, the *Lepanto*, *Re Umberto*, *Sicilia*, and *Sardegna* are at sea in the Mediterranean, how will you catch them? how will you take them? how will you prevent them doing their work? You have not a ship that could catch them; you have not a ship either armoured or unarmoured that can choose her place either to ram or fight them; you

have torpedoes. The theory of torpedoes is very good—they are very dangerous if they hit you, but they do not always hit the thing that is meant. What you want in the Navy is, first of all the intelligence department to tell you what your allies and friends have, in case they are ever to be your enemies, and then, if we are to be Mistress of the seas, as I hope we may be, we ought to have, for every possible ship that any possible enemy can have, another ship, or another two ships, to take possession of that ship, and be responsible for her. Gentlemen laugh at that, but I assure them that seems to me to be the way in which our Navy should be supreme. If the possible enemy has ships which you cannot overtake; which you cannot get near enough to, to fight, and which you do not know how to confine in their ports, because they may come out with their heavier artillery, and drive off the ships which you have there, if you have not the means of arresting these possible wrongdoers, then I say you are not supreme. It is for that reason I delight in Mr. Biles's paper, because it has given me an opportunity of saying this; but I differ from Mr. Biles in the possibility of comparing a totally unarmoured ship with an armoured ship, when the one can perform the work you may want her to do whatever she may cost, and the other cannot. I do not like to detain the meeting longer, but the question of coal protection, as a protection, I do not believe in. If you are to rely on your coal protection you cannot burn your coal. You must keep your coals for your protection; your ship must be protected whether she has her provisions in, or coals, or anything else. If your coals are burnt, she is not to be at the mercy of the first wrongdoer. I would urge on this meeting, and on everyone who desires that our Navy should be supreme, that they should take care that their policemen are as well mounted as Dick Turpin, and that he, on his black mare, cannot carry off the commerce of this country whenever he wants to.

Captain C. FitzGerald, R.N. (Associate): My Lord, I will endeavour to confine myself (with all respect to Sir John Hay) more closely to the subject than he did. I am somewhat under the disadvantage, or advantage—I do not know which it is—that the enemy know exactly what I am going to say before I say it. (Laughter.) I can see them all laughing.

The President: I am sure there are no enemies here.

Captain FitzGerald: Of course, my Lord, I mean friends who differ. But, before entering on the general subject of a comparison between the two types of construction, I shall beg in all friendliness to offer a few critical remarks on the paper itself. At page 336 the lecturer has put before us that in the *Aurora* class the height of the belt above the load water-line is 1 ft. 6 in., but Sir Nathaniel Barnaby informed us yesterday that, for reasons over which he had no control, the top of the belt would be 6 in. *under* water—is that so?—with 900 tons of coal on board.

Sir Nathaniel Barnaby: Yes.

Captain FitzGerald: This, then, is the ship that is put before us on paper; but the ship ready for service, as we now see her, will go to sea by the orders of the present Admiralty with the top of the belt 6 in. below the water-line! If that ship is put forward as the type of a belted cruiser, all I can say is, she is a travesty—a burlesque—of the principles of a belted ship, of endeavouring to protect stability or buoyancy by armour. I say those who think water-line armour is necessary for the protection of stability and buoyancy could not accept that ship as embodying their views in any way. There is one other point which, as a matter of criticism, I should like to call attention to. Mr. Biles has pointed out on page 337, "Thickness of belt on slope 4·69 in." I did not quite understand that. I hope he will correct me. I understood him to say it was 10 in. through one way and 4·6 through that way. Then he points out that as to the deck protection, which is a component part of this sloping

armour, "a plunging shot may strike the 2-in. deck in the belted cruiser in the part which is occupied by the sloped deck in the protective-deck cruiser, and penetrate the former where it would fail to penetrate the $4\frac{3}{4}$-in. deck of the latter." It seems to me that he is rather twisting the argument as to a plunging shot to his own views. I do not think he understands quite what a plunging shot means. If a shot came *straight* down, it would no doubt go through that deck much more easily than through this one. What we understand by a plunging shot is any shot out of the horizontal line, and I take it that a plunging shot at all the ordinary or probable angles is more likely to penetrate that deck than this. If you look at the trajectory of the present guns, it is exceedingly low. The 8-in. gun carries 1,100 yards with one degree of elevation. I do not suppose that any battles will be settled at a distance of very much over 1,000 yards. Therefore, I should say that the plunging shot theory is rather against this principle. It would be more likely to penetrate at that angle of slope, although it is $4\frac{1}{2}$ in., as against 2 in. here. That is all I have to say on that point. No doubt Mr. Biles will reply when he comes to it. I hope, my Lord, you will stop me when I have spoken long enough, but I feel that I could go on all day on this subject. It is a hobby of mine.

The President: I do not like to stop anybody. If gentlemen will stop themselves we shall be all the more grateful.

Captain FitzGerald: Now, as to this question of the distribution of armour. I do not want to go outside the general scope of this paper, but you cannot argue about armour unless you look at the question in all its bearings. Of course, we know armour is only intended to keep out shot. It has nothing to do with the ram or with the torpedo. Nobody has ever proposed armour to keep out a ram, although I think Sir Edward Reed has some designs for bottom plating for keeping out a torpedo, but although it is so intended, you cannot dissociate the whole subject of the defence of a ship, because if you put on a lot of armour you make her unhandy and slow, and consequently, as we are told, more liable to be destroyed by the torpedo. I might, however, contravert that statement, and say I think when once a torpedo is launched at a striking distance of 600 yards, nothing that a ship could possibly do after the torpedo is once launched would enable her to avoid it. At the same time we all admit that speed and mobility are desirable qualities to have in a ship. It appears to me that the general tendency towards the concentration of armour—taking the armour off (as it is in the old ships, the *Devastation* and *Dreadnought* type), and concentrating it in patches as in the new—has been arrived at from a misconception of the chances of battle. The whole question must be guided by the law of chances. What do you think you are going to have to resist in your ships? We know all about the ram and torpedo, but as to artillery fire, what fire do you think you are going to resist? It seems that the authorities have come to conclusions on false grounds. They put up an armour-plate at right angles to the fire of a gun of a certain size, and they pierce that plate. They then condemn that plate at once. They say the 6-in. gun pierces the 8-in. plate. Therefore, the 8-in. plate is no use. I think that is about as false a conclusion, looking at it in a practical light, as could possibly have been come to. The percentage of shot that will strike at right angles, and at point blank range, in an action will be very small. Vessels are not going to lay broadside on to the enemy, as they did in the old days. On the contrary, we shall have a system of rapid manœuvres all over the place, and I should say that 90 per cent. would strike at anything but a right angle, and, therefore, armour which will not keep out a certain sized shot at point-blank ranges will keep out very much heavier shot striking at the angles at which they are likely to strike, considering all the chances of a naval battle. If that is the case, armour of an exceedingly moderate thickness will do more to prolong the life of a ship than any arrangement of internal armour which has ever been devised by the talent of

our constructors. But there is, also, besides this large shot question, a development of artillery fire which has, I believe, in a large measure arisen in consequence of the concentration of armour—the taking it off in some places and putting it on thick in others—that is, the development of the quick-firing gun. To my mind that is the most deadly weapon we shall have to meet—even more so than the torpedo. You have guns now firing a six-pound shell that can fire ten aimed rounds a minute. I believe our neighbours are now making a 36-pounder of the same nature. That I do not know, but, at any rate, we have six-pounders.

The President: They are making them in Belgium at this moment.

Captain FitzGerald: I do not imagine they would be able to put the shot and the powder in the same cartridge, because it would be as long as that stick if they did (indicating the pointer). However, if you take into consideration the chances of battle, as I say, and it must all be based on the laws of chance, there are very few big guns afloat—a large ship would carry two or four—but she will carry a large number of guns of small descriptions, 4 and 6-in. guns, and three-pounders and six-pounders. I maintain that the chances of hitting with these guns are something like a thousand to one in their favour as compared with the big guns, not only on account of the rapidity of the fire and of the number carried, but also in consequence of the ease of pointing them. A ship in motion is an exceedingly difficult thing to hit with a big gun, even on a steady platform, and I believe that the big gun fad has been worked to death altogether. With regard to the injury that would be done to the side of a ship, 99 cases out of 100, or rather 999 out of 1,000 would be small holes, and not the cart and horse holes which Mr. Biles talks about. That, of course, *might* occur—pigs might fly. You *might* do it, and sink your enemy the first moment of going into battle, but what we must look at is, what are the chances? The chances are that the commanders of the two ships when they met each other would say, I will reserve the fire of my heavy guns, and get close alongside, and then I will polish him off with one shot. They begin loosing off with their small artillery, and they make a heavy smoke, whilst both the ships are rolling, and the captain of the turret does not know whether he is going to pass to port or to starboard of the enemy. If you have your gun on the starboard side, you will not have time to get it round so as to be ready on the port side, and in the excitement the big gun will probably miss. Now comes the point of what is the best protection, if I am only partially right in the assumption that the battle is more likely to be decided by light guns than by heavy ones. We come to the question, what is the best protection. Admiral De Horsey has very properly pointed out, that one of these ships which has only 93 ft. length of her bunker in the water-line belt may be riddled with small guns. Mind, you must not look at the water-line as a *line* like that, because the sea is often not very smooth, and you must take the water-line belt as being of considerable width—a wave falls as much as it rises, and therefore if you have a 3-ft. wave, it would be a 6-ft. belt, to say nothing of the roll of the ship. I do not accept that as a proper exponent of a water-line belt of protection. My view is that the belt of protection should come a great deal more above the water than below it. My reason for saying so is, that in firing at sea the great majority of the shot will strike above the water, and not below it. A shot strikes here, for instance, it would ricochet and go here, and will not go down in this direction (illustrating). There is, therefore, the chance of all shot which are originally directed to go above the water-line, and also the chances of all shot which fall short of the ship, which is a common thing at target practice, those would ricochet, and some would go in above water. Therefore I say the protection should be *here*. You should not provide against the remote chance of having a shot in there, so much as you should protect above the water, and save your ship in that manner. I know the great assumption of Naval Architects for going in for this style of protection, and for

protecting what they call the vitals of the ship, is that they do not believe in the sinkability of a ship, and they point to the records of the old wars, in which it was a very rare occurrence that a ship was sunk by artillery fire. I think that is a totally wrong assumption. In the old days a ship's side was wooden, and about 2 ft. thick, and the biggest gun was a 32-pounder. The shot went through, and after it had passed it left a hole which you could not even see through; you could not only plug it with the greatest of ease, but it actually plugged itself as the wood got wet, and the splinters became saturated and swelled; and, although the ships after the battle of Trafalgar were riddled all over, they took a long time to sink. The effect of a hole in a steel-sided ship is very different, as you know. A six-pounder will make a hole from four to six or eight inches in diameter, and carry the whole thing away. How are you going to deal with that? That would let in water enough to sink the ship in a very short time. Therefore, I am strongly of opinion that our Architects have gone wrong in assuming the unsinkability of our present iron and steel ships. There is just one more point as to armoured decks, which I want to allude to. They are given to us as a means of keeping ships afloat—I mean armoured decks under water, generally curved. These are to protect the vitals of the ship, and also to render a certain portion of the ship intact under water. As far as protecting the vitals of the ship goes, that can be done with very small patches of armour. I am all in favour of covering the crown of the magazines and the tops of the boilers with armour, to resist bursting shell; but, as to protecting the whole of the ship under water with an armoured deck to resist shell fire, I say distinctly it is an utter waste of weight. That part of the ship is already under water and sunk—it is paid for, and it is no use trying to keep it afloat—it is under water and gone. If you let water in above it, you would capsize her. If you keep it tight, and the water comes in above it, it will make her top-heavy, and turn bottom up. It does not require a scientific man to see that. My idea is, that if these armoured ships get riddled, the cry will be, "how are we to get this water down below to get it out of the ship with the pumps?"—the ship is going gradually over; we cannot stop the holes or pump it out on the deck. Send for the chief engineer to see if he cannot open some cocks to let the water below. (We always send for the chief engineer, who has the keys of everything.) I think there would be that difficulty in these armour decks. You want the water down below to pump it out; you must deal with it somehow. These gentlemen assume it is all right—that it is quite right to have so many tons of water washing about on the top of your deck. You cannot deal with it there, it will certainly capsize you, and what I want to point out is, that I believe all armour upon the deck, except what covers the crowns of the magazines and the tops of the boilers, is waste of weight. Suppose a shell bursts here, it is not over the magazine; and I would rather that it should come down *here*, or burst over the provision room and spoil the provisions, than that it should injure the vital parts of the ship. The conclusion I come to, looking at the matter as a practical seaman, is that I would rather have any form of side armour which would keep the water out, because when the water is once in you do not know what to do with it, or how to deal with it. I should prefer very moderate armour—6-in. armour, for the reason I have pointed out—the chance of shot striking at various angles. I should prefer an ordinary belt of 6-in. armour all round the ship to any device of internal armour which has ever been invented by the fertile brains of our exceedingly clever Naval Architects.

Admiral P. H. Colomb, R.N. (Associate): My Lord, this appears to be a Naval Officers' holiday, but I suppose the object of the paper is to draw Naval Officers' fire, in order that it may be duly replied to by those competent to do so. I will endeavour to confine myself to answering the question which has been put at the close of the paper. Most of what I would have said, had I been by myself, has been already more ably said by those who have preceded me, and I am exceedingly glad to find that my estimate of the Naval opinion, as far as it has been expressed to-day, has not been a wrong one—that

the Naval opinion coincides with that which I hold; and I think it is very fortunate that we have had a clear and distinct challenge to-day, in order that we may give, as we can, some reason for the faith that is in us. Practically, as I understand, we are asked to say whether it is worth while to give up 100 tons of displacement in a 5,000-ton ship, or thereabouts, for a particular form of armour, rather than retain it with another form. Sticking still to Figs. 1 and 3, which Admiral De Horsey took, and which I think give the fairest comparison, what the Naval Officer has to answer is—Why do you dislike No. 3, seeing that you get certain advantages out of it, and why do you like No. 1, seeing that there are clear disadvantages attending it? Captain FitzGerald, I think, has taken some of the points very clearly indeed as to the large and small guns, and as to the injury to which under ordinary circumstances the structures would be liable. I think we must never forget that soon after we began this armour question we were building ships with nothing but the two or the four heavy guns. Of late years, entirely, I think, due to the growth of Naval opinion, these ships, which formerly carried only heavy guns, are now being continually reinforced by numbers of lighter guns, and I quite agree with what Captain FitzGerald said about the chances of hitting. I do not think the chances of hitting about the water-line are so great after all, unless the fire is very numerous, because, although the shot between wind and water was not an uncommon thing in the old days, the change from round shot to rifled shot has made an enormous difference in the form that the ricochet takes. You may recollect that in the bombardment of Alexandria, hardly, I think, any ricochet shot took effect on our ships. We knew beforehand that it would be so, but it was then strongly noticed how the shot on striking short passed right up into the air over the ships altogether, so that the chances of a ricochet shot on the water-line are not so great as they were. But the chances of striking from the very numerous fire which may be directed from the small guns about the water-line are considerable. I follow Captain FitzGerald in believing that the great injury which would be done about the water-line would be done by the small guns, and not by the large ones. I will go as far as to say that I think you might fight half a dozen general actions now, and not one single ship would be hit vitally by a heavy shot on the water-line. The *Alabama* was sunk by *round*, not *rifled* shot and shell. The *Kearsage* had only one rifled gun—a 28 ton—out of seven. That being so, why do we prefer the armour carried up a foot or two above the water-line as side armour, and then a horizontal deck connecting its upper edges? I was never clear in my own mind about the matter until I witnessed an experiment which was to show me the advantage of the system, or something like the system, in No. 3, as against that in No. 1. I learnt a fact then which has dwelt ever since in my mind. I saw for the first time, and understood for the first time, that if you riddle any of those ships as a model above the water-line, and agitate the water, representing in fact a real ship in a seaway, that the water will not flow out of the ship as fast as it flows in. I saw there the model of No. 1, or something like it, with perforations above the water-line belt, and I saw that ship gradually capsize by the accumulation of water above the water-line on the armoured deck. The principle was, no doubt, as I have stated it, that in penetrating the structure of a ship the water does not rise only to the same level inside and outside, but that it will rise above the outside level of the water. Once you have established that, it seems to me you have established the destruction of the ship, unless that continued accumulation of water can be got rid of. Now, in the belted ship that capsized as I have described, no means whatever were arranged for clearing the water off the deck as it lodged there. I was much struck, I could not help being struck, by that experiment; but on returning home I began to think, Why! dear me, I have been accustomed in younger days to see many tons of water on the deck for a short period without being very much afraid of it. I was aware that the ship in which I had noted this circumstance had great stability, and was capable of withstanding

immense weights of water in the lee scuppers ; but I recollected that my reliance was not only on the stability of the vessel, but on the splendid system of freeing scuppers fore and aft the deck which never allowed the water to remain there for any time, and did not allow a superabundant accumulation. I said to myself, Dear me, that belted ship that I saw capsized in that way, capsized for want of freeing scuppers, and for no other reason. If she had had freeing scuppers the water would have flowed out of the ship faster than it came in, and consequently the ship would never have lost her stability. But the moment I came to think of the structure shown in No. 3, I thought to myself, how can you free the water flowing into that ship by the same means that you have allowed it to flow free out of the structure represented in No. 1 ? and I have not yet been able to understand how the water flowing into No. 3 is to find its way out. I am speaking now because I want to be answered. It is a very important question, and I hope that I shall be answered clearly, and that my mind at any rate will be set at rest. I am not able to see how in No. 3, if it be granted that the water does rise in the structure at sea as I saw it rise in the model above the outer level, that water is to be got rid of, if the pumps themselves cannot do it. But, in No. 1, I know of nothing that will hurt that ship, or destroy that ship if she has a proper arrangement of freeing scuppers fore and aft, unless it be penetration of the vertical armour belt, or of the horizontal deck. Those, my Lord, are the reasons that I have to give for the faith that is in me. There is no doubt whatever that the whole feeling of the Navy is in favour of No. 1, and against the system in No. 3 ; and I think it is most important, if the Navy is wrong in this belief, that the Naval Architects should show us, not only by tables, not only by drawings, but by experiments, which we in our uninstructed state can understand, rely upon, and accept, that we are wrong, and why we are wrong.

Captain J. D. Curtis, R.N. (Visitor) : I have been turning this matter over in my own mind. If a large portion of coal were taken out of that bunker the ship would capsize, or if she would not capsize she would make a list over to the contrary side, expose her bottom, and not be able to fight her guns —shot penetrating the coal bunker about the water-line would cause the coal to wash out. At Kinburn the *Hannibal* fired a 68-pounder shot through a massive piece of fir timber, and after the shot had passed through you could not get your finger through the place. I have always thought since then that a lining of fir, if it could be made fireproof, would be very valuable for the inside lining of a ship. The timber was an upright, supporting sods of turf and sand, forming a part of the Spit Battery at the mouth of the Dnieper.

Sir Nathaniel Barnaby (Vice-President) : My Lord, I find myself this morning in a somewhat curious position. The very able paper which has been read by Mr. Biles, attacks the principle of the design No. 1, which is the design of what is known as the *Undaunted* class, because we have too much armour on the sides. It is a novel position for me to find myself in, but I observe another peculiar feature in it. Some people complain that the world has gone on very fast since 1870. The world has gone on very fast indeed in the designing of ships of war since 1885—(hear, hear)—and the position of things is this, that since I left the Admiralty in 1885, not a single ship of war of any kind has ever been designed in any Navy that I know of, except our own, with armoured sides.

Captain FitzGerald : A good job too.

Sir Nathaniel Barnaby : That may be very well ; but we must look at it from another point of view. We must not assume that the gentlemen who are designing ships for other countries are great fools. I know them much better than the Naval Officers here know them. I know for example the designer of the ships about which our friend Captain FitzGerald is so exceedingly doubtful—those

great Italian ships which we have been hearing about from Sir John Hay, with 18 knots' speed. You need have no fear about them, Sir John Hay. Captain FitzGerald says they are of no use whatever; but I have the pleasure of knowing the designer of these ships, Mr. Brin, and anybody who knows him knows a most distinguished Naval Architect. But it is not only in Italy that large ships with unarmoured sides are being built. Let us turn to our friends in France. What are they doing? Look at their programme for next year. You will find they are going to lay down and build a large number of protected ships, not one with any armour on the sides; but all of them on the principle that Captain FitzGerald condemns so heartily. You must not suppose that the ships which are being built everywhere by these foolish persons are exactly like the ships which have been placed before us by Mr. Biles; they are not. In most cases the deck which you see drawn there, sometimes under water, and sometimes on the water, lies above the water as high as it is shown in design No. 1, and in the cases where the deck by intention starts by being under the water, they do not rely wholly on coal, but they use some solid packing in the form of cork or some other substance. That again Naval Officers may say is a very frail thing to depend upon. It may be so, but I am speaking of what is done, not in our own Navy, but in foreign Navies. You have to observe that in the ships which Mr. Biles has shown, and for which he has said what he has to say, that he offers to us, instead of what we have in design No. 1 for the British Navy, a higher speed, and I think that that has been somewhat overlooked by some of the speakers. I wish to point out another thing, which is this: that Captain FitzGerald, in speaking of No. 1, says that she should not be shown in that way, but she should be shown with her deck 18 in. under the water.

Captain FitzGerald: 6 in.

Sir Nathaniel Barnaby: You meant 6 in. Yes. Now, observe that in these ships which Mr. Biles has shown us, he talks about carrying a thousand tons of fuel, and if you put in a thousand tons of fuel, they will be nearly 2 ft. deeper than you see them. He has put into these ships 500 tons of fuel at the draught of water shown, and not a thousand. He has not supposed for a moment that anybody is going to insist on his starting with a thousand tons of coal in, but he supposes you are going to treat him, as Mr. White told us yesterday that he expected to be treated, viz., that he expected that the ordinary supply of fuel would be about half that for which he made provision in his bunkers.

Mr. W. H. White (Vice-President): Excuse me, for which I guaranteed the speed.

Sir Nathaniel Barnaby: I am not prepared to defend the ships which are shown by Mr. Biles, and which he desires you to consider to be better than those for which I am responsible as shown in figure No. 1. We should, however, bear in mind clearly just how the matter stands with regard to foreign powers. Sir John Hay said a thing which I dare say you may have observed. It is an idea which I often hear expressed by Naval Officers. Why, they say, do you talk about relative expense? and why do you talk about relative size? Mr. Biles represents, gentlemen, a firm that have to design ships under competition for foreign governments—competition as to price; and he has learned that the question of price underlies the whole thing. And the question for the Naval Architect must always be: That is the money; what is the greatest amount I can get for it? That is the way he puts it before you, and I observe that the Naval Officers generally take the view that Sir John Hay does: "Oh! you should not consider the money; you should not consider the size; give us the best thing you can." But, gentlemen, if Mr. Biles did that, his firm might shut up. They would get no orders. I observe that in the ships which Mr. Biles has shown, he starts with the same metacentric height as

with class No. 1. I think that is not quite fair. I think that there ought to be, especially where the deck is by design under the water, a larger metacentric height than there is in the case of the ships where the protection comes right out to the full breadth of the ship. Captain FitzGerald said that we assumed unsinkability for the steel ships. Not at all. We know a great deal better than that.

Captain FitzGerald: Comparative unsinkability, I think I said.

Sir Nathaniel Barnaby: No; nor comparative. And one reason why we carry the armour through from end to end in this under-water deck, and do not content ourselves with a patch here and a patch there, is because we know that if we did not do it the ships would sink quickly when wounded. It is carried through for the purpose of keeping the ships afloat. And you must observe there is a very great difference indeed between the admission of water near the load water-line, and the admission of water into these parts of the ship which lie below, as it affects the question of how long the ship will keep above the water. Then Captain FitzGerald also pointed to the immersion of the armour below the water, and he said he thought the armour ought to come as far above as it goes below; and he showed you his reason for that was that the shot would more often be deflected upwards than downwards. Of course there is no question about that; but he forgot to tell you that a shot which comes into a ship above the armour cannot be a fatal one, but the shot that comes in under the armour will almost certainly be a fatal one. The principle which, rightly or wrongly, I have always had in my mind has been this: take care that the enemy shall not be able to disable you by any single blow. Now, the gentleman who attaches so much importance to the quickness of the fire of these small guns puts that consideration wholly on one side. I say that the destruction of a ship by means of the firing of small guns, however rapidly you may consider that to be effected, must be a question of time, and that while that is going on you have, or ought to have, your own small guns to reply to them; but that a ship which can be disabled or sunk by a single blow, whether it be by torpedo, or by ram, or by a gun, is badly designed, if she is as big as the ship that she is fighting. I am quite aware that it will be of no use for me to attempt to debate here with those Naval Officers who represent a view of the question which I greatly respect. But I have thought about it as much as they have, and I have placed before you the views of people whose opinion I respect more than I do my own very often, namely, the people who are designing ships of war for foreign governments, and I am content to leave the question where it now stands. I would call your attention, if you please, to the second sentence in Mr. Biles's paper, in which he describes what he calls a belted ship; and you will observe that he nowhere indicates that in that belted ship the armour should rise above the water-line. He is quite right. It is a proper description of the belted ship, and it affects the question which was being debated here yesterday. I do not know that I have anything else to say, except perhaps this, that the ships which Mr. Biles puts before us you will observe have no armour of any kind visible upon them. They are fair representations, with the exception that I have just quoted to you, of what may be called unarmoured ships, protected unarmoured ships; but they do not any of them represent ships which are being built at this present moment, and I should not be prepared to defend any one of them as it stands.

Admiral E. S. Boys (Visitor): My Lord and Gentlemen, I am sorry that our beautiful, snowy, spring weather prevented my being here to-day in time to hear the whole of this paper, but I have heard the discussion, and perhaps I may be permitted to make one or two remarks upon the practical gunnery part of it. In the first place, respecting Captain FitzGerald's remarks as to the plate he has drawn there and the shot which penetrated it, I think he has led us to believe that firing directly at those plates is

intended to show the probable destructive effect upon a ship. Well, I may tell gentlemen here, though probably many of them know it, that the reason for only firing directly at targets is simply for the purpose of testing the projectile and the quality of the plate. The great object of the Royal Naval Architect is to get a plate target as strong to resist attack and as light as possible. Lightness combined with resisting power is the quality to be obtained in the construction of armoured ships. With regard to riddling a ship's side by means of small, quick-firing guns, even three or six-pounders, my Lord, I do not believe in it. I think that no three or six-pounder would have more effect on the side of a ship such as those under discussion than firing peas would have on that board. The small holes which might be made in her would be comparatively few, and certainly not numerous enough to let in water sufficient to affect her stability, or risk the safety of the ship. If a ship were, as Sir Nathaniel Barnaby said, to remain under a steady fire for a very considerable time, a certain line might be drawn along the side through which shot might penetrate, and the side of the ship be cut through, but in the present condition of naval warfare, where ships will pass each other most rapidly, I do not believe that riddling will take place from small guns, or even from guns up to 6-in. calibre. The small machine and quick-firing arms put into our ships nowadays are principally and chiefly for the purpose of defence against torpedo attack, of firing at the upper unarmoured parts of ships, with a view to projectiles entering ports or conning towers, damaging gun-mountings and injuring crews, and not with the intention of letting a large quantity of water into the ship. Then again, Admiral Colomb has made an observation to the effect that he does not believe any of the large projectiles of the present day will strike between wind and water, and he instanced the bombardment of the forts at Alexandria. My Lord, I do not think we can accept that. I think there is a chance of such a thing happening, and that we should do our best to provide against it. I may illustrate this by mentioning a case which we all recollect, that of the action between the *Kearsage* and the *Alabama*. A shot from the *Kearsage* did strike the *Alabama* in that position. A shell struck the ship between wind and water, and sank the ship. Such a thing may happen again. I will finish what I have to say by adding that, as a Naval Officer, on general principles, and from the drawings I see there, I much prefer keeping the shot out altogether by any means we can devise, even by incurring additional weight and expense, than allowing them to enter, and rendering them as innocuous as possible after they do get in.

Mr. W. H. White (Vice-President): My Lord, I wish to come to the diagrams before speaking, because I can only in that way shorten very much what I have to say. I take it that, although the discussion has been very general to-day, the point we are really considering is this: What is the best system of protecting a certain region in the neighbourhood of the water-line, which is of very moderate breadth in relation to the total depth of the ship? I take that to be the essential point of discussion. Whether we have an armoured belt, a belt of vertical armour, or whether we have what is called "inner" armour (a sloping deck), we are really in a position to start with the idea that the vertical depth of the region to be protected shall be the same in all cases; also we may assume that a portion of the protection shall be horizontal or approximately so, and that the thickness of the horizontal portion shall be the same in all cases. The question really to be discussed is, is it wiser to throw the disposable weight of protective material into a horizontal deck and a belt of thick vertical armour, or to fit sloping armour within the ship, having its lower edge at the same depth as the lower edge of the belt, and to build up a light side above these slopes, making arrangements either by the stowage of coal or of cork, or cellulose, or some water-excluding material, to prevent the access of considerable quantities of water into the angular spaces between the slopes and the thin sides. Now, I trust I have made myself clear that this is the point upon which I am going to talk. I am not going to talk about whether

the *Italia* or the *Orlando* are good ships or bad ships. I am simply going to speak to this : What is the best method for protecting this vertical region in a ship, having regard to cost and other seagoing and fighting qualities. We will assume another thing, although I am bound to say that Naval gunners do not, any more than doctors, entirely agree, but we will assume that the trajectory of modern projectiles is practically horizontal. I quite agree with Captain FitzGerald that plunging fire, except from forts or places of that nature, should not be considered; and we will take into account the fact that in future actions, besides the attack by armour-piercing guns so-called, there must be encountered the hail of projectiles from the quick-firing guns which are of comparatively recent development, but which have already grown from the six-pounder up to the 6-in., and which the mechanical genius of our gun-makers will probably allow to go further still if that is desired. It is not theory; it is a question of fact that 30-pounder and 40-pounder quick-firing guns have already been made in this country, and fired at the rate of something like twelve or fifteen aimed shots a minute. And 6-in. guns of similar type are being made which, in muzzle velocity and accuracy of range, will compare favourably with guns of the same calibre not made as quick firers, and will possess special armour-penetrating power. These are facts and tendencies which we cannot disregard in this discussion, and all these considerations must have a bearing on what is the best course to pursue in ship construction and protection. Now, coming back to the essential point with which I began, the first thing I wish to say is this : For myself, I do not believe in any mystic charm in the 6 or 7 ft. of depth protected in a belted ship out of the 30 or 40 ft. of her total depth. The part above the water and above the armour, and the part below the armour and below the water, these two parts are essential to the floating, to the stability, and to the behaviour of the ship. To talk as if 5 ft. of height above the still water-line, or 5 ft. depth below the still water-line, embraced the whole portions of the structure which need to be considered, or to assume that there is a mystic point below which no attack by artillery fire shall be considered to be likely to take effect, is to my mind absurd. On this diagram we have a ship of 56 ft. beam, with the lower edge of armour 4 ft. below the water; an angle of heel of 8 degrees only in perfectly smooth water brings this belt to the water surface, making no allowance for the rise and fall of the waves in a seaway, to which Captain FitzGerald, as a practical seaman, very properly drew attention, or for the wave-profile along her side due to her swift propulsion through smooth water. With such a belt, therefore, a very moderate angle of roll or rise and fall of water surface brings the thin bottom-plating below the belt armour of water into a position where it may be exposed to gun fire. While I quite believe that it is the height of absurdity to suppose that any intentionally aimed shot is going to pass below the lower edge of armour, with ship upright in still water (indicating), it is equally unwise to assume that no shots will pass below and damage the unprotected bottom. Now, coming to the top again, What is the limit of protection in nearly all existing armoured ships of recent construction with vertical armour on their sides ? It is perfectly well known to everyone who has studied the question that the limit of protection is in the *strength of the decks* of the latest ships belonging to our own or foreign Navies. This is true on the assumption that the trajectory of modern projectiles is practically horizontal; but, taking into account the angles of rolling at sea, which commonly occur in by no means heavy weather—such angles as steady ships commonly reach in weather when an action might be fought—the covering decks at the tops of the side armour are relatively weaker against the attacks of projectiles from modern guns than are the sides which are armoured; and I emphasise the fact, in order, as far as may be, to clear away debateable matter. These are, my Lord, I believe, indisputable facts and not opinions. Now, then, we start with the limit of protection in the deck, and we have to consider what is the best way on the whole, in association with securing other necessary qualities, to protect this vertical region in the ship,

which, by common consent, is looked upon as that where protection should be massed. In one particular I regard these diagrams in the paper as unnecessarily misleading, at least for the kind of protected ships which I have been accustomed to design. Let me put a line here (drawing line on diagram so as to bring protective deck above water). I do not know whether the line I have drawn can be seen; but in actual ships which I have designed and built, with the protective deck above water at its central and horizontal portion, a very moderate weight of coal (not exceeding 100 tons) left in the angular spaces above the sloping armour practically prevents the possibility of the admission of much water to those spaces. Supposing the whole of these angular spaces above the sloping armour thrown open to the sea, the amount of water that can enter therein is not worth mentioning, if a very moderate amount of coal is kept there; and the "sinkage" of the ship, if the spaces are conceived to be thrown into free communication with the sea, is not worth mentioning. Starting, if you please, with the type of protected ship that I have sketched, the danger of sinkage from the admission of water above the protective deck is made exceedingly small, and therefore no serious disturbance need be anticipated when the light sides above the protective deck are shot through, in trim, draught, or stability. That is a perfectly realisable condition. Then you have to consider another point, which I think has been somewhat overlooked in the remarks of the gunnery officers to-day. We will suppose that this (indicating) is the water-line, and that the belt armour goes 18 in. or 2 ft. above water. Well, we will start with the same idea, say, that the horizontal part of the protective deck is 18 in. or 2 ft. above water in a vessel which has side slopes, instead of vertical belt armour.

A Member: I thought you were speaking of Mr. Biles's ships.

Mr. W. H. White: I am not talking about his ships, and I leave to Mr. Biles the defence of ships having their protective decks entirely under water. I am taking protected vessels which are in existence, and which can be compared with belted ships, and I am assuming the protected region in both cases to have the same vertical height and the same portion of this thick horizontal deck in relation to the water-line. Now, if we adopted the views expressed by some Naval officers in this discussion, who practically say, "We cannot attack anything below the water-line with modern rifled projectiles," it will be seen that in both types of ships the region above water protected by vertical or sloping armour will have a vertical height of $1\frac{1}{2}$ to 2 ft. only, which is a rather narrow strip out of the total depth of the ships on which to hang the sweeping condemnations of one system of protection and exaltation of the rival system of vertical armour to which we have listened. I do not accept the view that the parts of a ship below her ordinary still-water load-line should be treated as invulnerable to projectiles, and have given my reasons for that opinion in the preceding remarks; but if that doctrine is accepted, then, I repeat, the difference between the two types of ships resolves itself into the chances of hitting a strip of side which is eighteen inches or two feet wide from the water surface to the top of the protective deck. That is the problem reduced to its simplest form, as far as I can see it. I cannot help thinking that if these views are correct, and if the conditions to which I have referred, in connection with the position of the deck in relation to the water-line, are fulfilled, a better protection on the whole is secured by putting a given weight of material into oblique or sloping deck armour, rather than into vertical side armour.

Captain FitzGerald: May I explain for one moment? I do not want to interrupt, but we do not accept that as a type of belted ship. This is only a travesty of it. The belt should rise higher above the water, to be of any protective use.

Mr. W. H. White: I am coming to the question of the narrowness of the belt. Let me again say

I am taking existing ships for the purpose of comparison of the two systems of protection. That is the point of Mr. Biles's paper. Not whether the belt is broad enough; but, having a given width of belt, how best to dispose the protecting material. I again say that, subject to these governing conditions being fulfilled in the design, this does appear to me to be on the whole the best disposition of a given width of protecting material. Now, I will go further. On the whole, taking the trajectory of projectiles as horizontal, and taking what we know of the power of armour-piercing steel projectiles, I say that the oblique defence has a better chance of escape from perforation than the vertical, more especially when you take it that, under most conditions, there will overlie the oblique defence a mass of coal, which, against many forms of projectile, will act as a most effectual "stifler." I have not said a word yet about the question of cost. Now I come to that important consideration. Speaking roughly, the cost of buying and fitting a given weight of vertical armour, such as would be used in a belted cruiser, may be taken as from five to six times what would be spent in buying and fitting an equal weight of oblique deck armour. Now, as to whether the belt in these ships should be increased in width, that is the point which Captain FitzGerald raised. About that I would like to say a few words. I can imagine that if the mechanical genius of the country were to be arrested, and we were to have no more powerful quick-firing guns than we have had, or are now expecting, then there would be a good deal to be said for Captain FitzGerald's view in favour of extending the area of armoured protection and reducing the thickness. But looking to the inevitable tendencies of the present, and to our experience in the past, I do not agree with him. To spread out the armour over large surfaces in order to meet the fire of existing quick-firing guns is just simply to begin the story over again which the last twenty-five years have had to tell. It would begin with existing quick-firing guns against comparatively thin armour, then pass to more powerful quick-firing guns and thicker armour, and probably be followed by reduction in area of the armoured surface, and the whole story over again. This paper deals with subjects upon which I have thought a great deal (as Captain FitzGerald has). We have arrived at different conclusions, but I am sure we respect one another's opinions fully; but I do most distinctly challenge—and I say that of set purpose—the statement that the feeling of the English Navy is entirely against the protected class of ships. I make that assertion with intimate knowledge of the fact that there are a great many officers who share Captain FitzGerald's opinion, and, so far as I can recall to-day's discussion, his opinion in that matter has been supported by all the Naval officers who have spoken. But to my certain knowledge there is a great body of opinion amongst some of the most experienced gunnery officers of the Navy in favour of the oblique system of defence (No. 3), as compared with the vertical (No. 1). And if it is to be a question of armour protection, as securing the buoyancy and stability and the good qualities of a ship, then I say that the question of vertical extension which Captain FitzGerald has raised is of infinitely greater importance than the question of the longitudinal extension of the belts in the ship. I may conclude by saying that when tenders were invited for the belted cruisers of the *Orlando* class, and when I necessarily had regard to these mean commercial considerations which have been alluded to here to-day, being then at Elswick, and trying to turn an honest penny for my employers, I took the trouble to see what could be done on the dimensions of the *Orlando* class, provided that I passed from vertical armour to the other system. I found that a ship of exactly the same size, with the same armaments, the same engines—nothing changed, excepting the system of protection, might take on board 200 tons more coal, and would cost £20,000 less, than the belted ship.

Admiral De Horsey: Might I be allowed to say two words—with the indulgence of the meeting?

The President: Only by way of explanation. I cannot allow a second speech.

Admiral De Horsey: No, my Lord. It is merely this: that we have been discussing the question of a ship whose armour was above the water as against one whose armour was below the water, and we have therefore said that one ship would float and the other would sink. Now, Mr. White has drawn a new water-line, and under the altered circumstances of the deck being above the water it might alter one's whole opinion.

Mr. J. H. Biles (Member): My Lord and Gentlemen, the discussion upon this paper has covered so much ground, and it has been so ably covered, that I am afraid there is very little that I can say, beyond personal explanation, that will contribute anything to the discussion. Sir Nathaniel Barnaby has pointed out what is really the basis of the whole paper—for a given sum of money, which is the best ship? Is it that ship? or is it this ship? The question then resolves itself to this: Is this type of protection as good as that type? because, if it is not, if the two types of protection are not equal, then that ship is undoubtedly a better ship. And that brings me to this remark, that the fact that that vessel has increased speed and increased gun power enables her to place herself in such a position relatively to that vessel that she may at one single blow completely disable this vessel. Now, I think that the importance that is being given now, and has always been given, to the question of speed must be set to balance anything that you can say against the question of flooding these parts, because that vessel may be able to place herself in such a position that she can make this vessel totally out of the combat, so as to be completely unable to make use of this quality which is claimed for her, of being able to have greater buoyancy and stability on account of this armour.

Captain FitzGerald: How is she to do it, by running away?

Mr. Biles: By ramming, and also by the greater gun-power that she has. She has four of these heavy guns, against two of that vessel's guns, and she has double the chance of hitting. Now, as to the question whether this deck is to be above the water or on a level with the water, there is really very little difference in the design. There is practically no difference in the design in making the deck up above the water; that is to say, when we come to the basis of comparison, of course, then it introduces very little difference indeed into the thing; so I am rather sorry I did not lay a little more emphasis upon that fact. It was in my mind, but I did not put it in the paper. But the view I take of the matter is this: that this question of talking about a thin line as being the water-line of a ship is not a practical view of the matter. The water-line of a ship is something from about there up to there (indicating). That is the sort of thing; and whether that takes a little bit up, or a little bit down, really does not enter very materially into the question, because you always have to take into account the buoyancy of the substances that are above that deck which will always help the ship. If the coal is not there, then the vessel will not float to this line, but she will float on some line lower down, and then she will have the buoyancy that is necessary when she has no coal. With respect to Captain FitzGerald's remark about the plunging shot, or his criticism about what I said in the paper, that (indicating) is the thickness of the sloped armour, and that is the thickness of the horizontal armour. You can easily see that there are certain angles at which this armour here offers greater protection than does the flat armour, and those angles, I think, if you consider the matter, are more likely to occur than the angles in which this is a worse protection than that.

Captain FitzGerald: That is the point I exactly controvert. I say, in that case which you have shown, it is in favour of the horizontal deck. The angle is so much better.

Mr. Biles: Your point is that those shots were practically horizontal. They had a very low trajectory, but Mr. White settled that question by pointing out the big angles of roll of these ships. Your vessel is as often inclined at an angle of thirty degrees towards the shot that is coming as it is inclined in the opposite direction. I think most of the points that I had noted down here have been effectively dealt with by Sir Nathaniel Barnaby and Mr. White, and I hope, therefore, you will think it is unnecessary for me to occupy the time of the meeting by discussing them further.

The President: Gentlemen, I am quite sure you will all agree with me that we have had a splendid fight. I think it is the finest game of Kriegspiel that has ever been played either in this theatre or in any other, and I am only thankful to Heaven that I am not the umpire. (Laughter.) But the descriptions have been so graphic, and the energy thrown into the arguments so great, that we have seen ricochet shots, we have seen perforated sides of vessels, we have seen sinking ships, and we have seen all the conditions of a Naval battle, except, thank goodness, the cries of the wounded. I am sure, gentlemen, you will allow me to return thanks to Mr. Biles for raising, by his most able paper, certainly the most interesting, and probably the most popular, discussion upon this difficult subject that has been as yet held anywhere in this kingdom. I congratulate you all upon this morning's work. I am sure you will allow me to return our grateful thanks to Mr. Biles and to all those Naval Officers and skilled Naval Architects who have joined, not weapons, but hands, and fought so evenly and so well during the course of this discussion. (Applause.) Gentlemen, I am sure, after the able speeches we have heard from Admiral Colomb, that you will elect him as an Associate of this Institution.

ON THE SHIFTING OF CARGOES.

By Professor Philip Jenkins, Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The danger arising from the shifting of cargoes has long been recognised. Prior to 1875, when the first Act of Parliament dealing with the subject was passed, losses from this cause had become so numerous that underwriting associations found it necessary to issue instructions regarding the stowage of grain cargoes, and the precautions taken to prevent shifting were generally in accordance with those instructions, and under the supervision of their surveyors. Much valuable information as to those instructions, as well as on the subject of grain cargoes in general, is contained in the very able paper read by Mr. Martell before this Institution in 1880.

In 1875, however, during the passage through the House of Commons of the Merchant Shipping Act of that date, Mr. Plimsoll succeeded in introducing a section by which no cargo of which more than one-third consisted of any kind of grain, corn, rice, paddy, pulse, seeds, nuts, or nut kernels was allowed to be carried on board any British ship, unless such cargo was contained in bags, sacks, or barrels, or secured from shifting by boards, bulkheads, or otherwise. The same requirement was practically renewed in the Act passed in the following year, but was repealed in 1880 on the passing of the Carriage of Grain Cargoes Act, based upon the recommendations of a committee appointed earlier in the same year to consider the question.

According to the later Act, which has remained in force to the present time, no grain is allowed to be carried in the 'tween decks in bulk if the vessel be laden on the coast of North America, or in the Mediterranean for a port outside the Straits of Gibraltar, except such as may be necessary for feeding the cargo in the hold, and it must be contained in properly constructed feeders. If grain be carried in bulk in the hold, and proper provision for filling up the same with feeders is not made, not less than one-fourth of the grain carried in the hold must be in bags supported on suitable platforms laid upon the grain. The latter regulation does not apply, however, to oats, or cotton seed; nor to sailing vessels of less than 400 tons register not engaged in the Atlantic trade; nor to ships laden at a port in the Mediterranean or Black Sea, if

certain requirements as to shifting boards, &c., are complied with; nor to vessels in which the grain cargo does not exceed one-half the whole cargo, the remainder being of such a nature as to admit of stowage that will prevent shifting. Where grain is carried in the hold or 'tween decks, whether in bags or in bulk, the hold, or the space between decks, has to be divided by sufficient shifting boards extending from deck to deck, or from deck to keelson.

Notwithstanding the enforcement of these stringent rules, which must have had an important effect in reducing the number of vessels lost, the annual loss of life and property from grain-laden vessels still continues to be very large. During the three years ending in 1877, 93 grain-laden British vessels foundered or were missing, the number of lives lost being 833. In the next three years the number of vessels so lost rose to 111, and the lives to 946; but in the next triennial period, during the whole of which the Carriage of Grain Cargoes Act was in force, the numbers were reduced to 74 ships and 854 lives.

It should be observed that, although the loss of life was greater during the three years from 1881 to 1883 than from 1875 to 1877, the grain trade had grown considerably during the intervening period, and there can be no doubt, I think, that if the total quantity of grain shipped during each of the periods in question were known, it would show that the requirements of the Act of 1880 have been beneficial in reducing the percentage of vessels lost from this cause. But the Act of 1880 does not prevent the shifting of cargoes; it tends rather to minimise the disastrous effects of shifting. The reports of inquiries regarding the loss of grain-laden ships at sea by foundering, clearly prove that a very large proportion of such losses have been brought about by the shifting of the cargoes which the lost ships carried, notwithstanding that they had been laden in accordance with the requirements of the Act. From the excellent summary, too, printed at the end of the paper read by Dr. Elgar at the Liverpool meeting of this Institution last year, it may be seen that in more than one-half of the instances where survivors from grain-laden vessels that had foundered were able to give an account of the circumstances under which loss occurred, the disasters were attributable primarily to the shifting of the cargo, and to the consequent list which the shifting produced.

This fact led me to attempt an investigation of the effect which the motion of a vessel at sea has upon the tendency to shift, and as the results at which I have arrived may prove of some interest to the members of this Institution, I have ventured to lay them before you in the form of a paper.

When wheat, barley, or grain of any other description is heaped in large quantities upon the floor of a warehouse, the front surface of the grain will assume a slope, if the heap be made high enough, at which the action of gravity upon the surface particles tending to cause them to slide down to the floor is just balanced by the frictional resistance to motion. If the slope be made steeper, grain will run down from the upper part

to the lower, until the same inclination is again reached, while if the slope be made less steep than the limiting angle, equilibrium will continue to be maintained. As is well known, the maximum angle which the free surface of the grain can assume with the horizontal plane is termed the "angle of repose."

I need not observe that if such cargo be placed on board ship in still water the same law will continue to hold, and if the surface of the grain be trimmed horizontal for the upright position of the vessel, and she be then steadily inclined, not until the inclination becomes equal to the angle of repose will any shift of cargo take place. As soon as that angle is attained sliding ensues equally over the whole of the surface. So far as I am aware, no data exist giving the angle of repose for wheat, barley, or similar cargoes, and this is the more remarkable because, on the value of that angle it in a great measure depends whether shifting at sea will take place or not.

The determination of the limiting angle for the different species of grain or other homogeneous cargo occupies but little time or labour. Quite recently I made some measurements of the angle of repose of three kinds of bulk cargo, in the Queen's Dock, Glasgow, with the following results :—

Species of Cargo.	Angle of Repose.
Wheat	$23\frac{1}{4}°$
Indian Corn—1st kind.....	$26\frac{1}{2}°$
Do. 2nd do.	$28\frac{1}{4}°$
Peas and Beans mixed	$27\frac{1}{2}°$

It will thus be seen that the angle of repose for grain cargoes is not greater than the angle many of H.M. ships of war have been found by careful observation to roll through, and hence on board such vessels grain having a free surface would shift from inclination alone. But probably steam vessels which have but little stability, when laden with cargoes such as the above, seldom roll through such large angles as would involve shifting, if shifting were governed by the inclination solely, as in still water; and if this be so, the shifting that so frequently takes place must be due to some cause or causes that combine with the tendency which gravity creates to enable the surface particles to slide down hill before the inclination is reached which limits their motion when under the action of no forces but those which gravity and frictional resistance to motion supply.

To fully appreciate the effect which the motion of a vessel at sea has upon the equilibrium of the surface particles of grain cargoes, it is necessary to examine separately the effect of each species of motion. The case of a vessel at sea may be said to differ

from that of a vessel inclined in still water, in that the waves she encounters cause her to roll, to have a heaving motion, to pitch and 'scend, and to receive shocks through masses of water striking the sides. In addition, when rolling passively in the trough of the sea, the vessel and her cargo acquire the orbital motion of the particles of water lying in the effective wave slope, and the tendency is, therefore, for the vessel to place her masts along the normal to the effective wave slope, and the free surface of the cargo consequently in the direction of the tangent. Some of these phenomena obviously have the effect of increasing the tendency which the cargo has to shift, while as regards others the resultant action is not at first sight so obvious. I propose to consider them in the order in which they are set down.

First as to rolling. So far as the nature of the effect produced by rolling alone upon the tendency of the cargo to shift is concerned, we may equally well confine our attention to the case of a vessel in still water. Let us suppose, therefore, that a vessel containing grain, which has a free surface level when the vessel is upright, is set rolling in still water through large angles, and for the sake of simplicity let it be supposed that the motion is taking place around a horizontal axis passing through the centre of gravity. When the limit of the roll to port or starboard is reached, and when, therefore, apart from other considerations, the greatest tendency to shift exists, so far as inclination of surface itself is concerned, the resultant action of gravity and of the surrounding particles on each of the surface particles is an accelerating force tending to push it back towards the position it occupied when the vessel was upright. As we shall see, the effect of this force is to increase the tendency to shift, or to decrease it, according to the position of the surface particle in the vessel.

Let $a\ a$, Fig. 1 (Plate XXIX.), be the free surface of the cargo, and G the centre of gravity of the vessel. The moment tending to right the vessel at the instant the greatest inclination is reached will be W . G Z, where G Z is the length of the righting arm at that inclination, and $\frac{d^2\theta}{d\,t^2}$ will represent the angular acceleration, θ being the inclination of the vessel from the upright. If m be the mass of any small element of the cargo in the surface at P, its linear acceleration will be $\rho\,\frac{d^2\theta}{d\,t^2}$, ρ being the distance of the particle from G. The moment of the moving force on the particle at P is $m\,\rho^2\,\frac{d^2\theta}{d\,t^2}$, and the sum of all such moments for ship and cargo must be equal to the righting moment, or

$$\Sigma\, m\,\rho^2\,\frac{d^2\theta}{d\,t^2} = -\,\mathrm{W}\,.\,\mathrm{G\,Z} \qquad (1)$$

This is the well-known formula employed in the investigation of the rolling of ships. Since $\Sigma\, m\,\rho^2$ is the moment of inertia of the ship and cargo combined, we may write—

$$\mathrm{M\,K}^2\frac{d^2\theta}{d\,t^2} = -\,\mathrm{M}\,g\,.\,\mathrm{G\,Z}, \qquad (2)$$

where M is the whole mass, and K the radius of gyration. The angular acceleration is therefore given by the expression—

$$\frac{d^2\theta}{dt^2} = -g \cdot \frac{GZ}{K^2}, \qquad (3)$$

and the linear acceleration of every particle is found by multiplying this quantity by the distance of the element from the axis through G. To produce such an acceleration, force has to be applied in a direction at right angles to the plane containing the axis and the particle, or, what is the same thing in effect, the forces acting on the particle become correspondingly modified.

In the case of a surface inclined and at rest, Fig. 2, (Plate XXIX.), any surface particle may be considered to be acted on by three forces, viz., its weight w downwards, a normal force R supplied by the grain with which it is in contact, and a force F due to frictional resistance opposing the tendency of the component of the weight in the direction of the surface to cause the particle to roll down hill. In such a case, therefore—

$$F = w \sin\theta = R \tan\theta \qquad (4)$$

In the case of a ship that has reached the limit of her roll to port or starboard, the forces that really act upon a surface particle P on the emerged side (Fig. 1) are the weight w, the frictional resistance F, and such a modification of R as will enable the necessary acceleration to take place. No error will be introduced, however, if we suppose w, F, and R to act as before, and apply at P a force at right angles to G P sufficient to cause the acceleration. The particle at P may therefore be considered when the limit of the roll is reached to be acted upon by its own weight vertically downwards, by a force R at right angles to the surface, by the frictional resistance F, and by a force $\frac{w.GZ}{K^2}\rho$ at right angles to G P sufficient to produce of itself the linear acceleration $\frac{g.GZ}{K^2}\rho$ already deduced. Call the latter force T. By D'Alembert's principle, if T be reversed, as in the diagram, the system of forces will be in equilibrium. Hence, resolving along $a\,a$ and at right angles to it we get—

$$F = w \sin\theta + T \cos\phi \qquad (5)$$
$$R = w \cos\theta - T \sin\phi, \qquad (6)$$

θ being the inclination of the surface to the horizontal plane, and ϕ the inclination of the line G P to the middle line of the vessel.

If the angle at which slipping takes place when the vessel is inclined and at rest be called ψ, slipping will occur under the action of the accelerating forces when

$$F = R \tan\psi.$$

Hence, by substituting, we get—

$$w \sin\theta + T \cos\phi = (w \cos\theta - T \sin\phi) \tan\psi$$
$$\therefore\ w \sin(\psi - \theta) = T \cos(\phi - \psi), \qquad (7)$$

an equation which gives θ the inclination at which slipping begins. Since, however, T contains G Z, which changes in magnitude with change in θ, the equation can only be solved by a process of trial and error, except in cases where the value of G Z can be expressed in terms of θ.

The particle P, selected in Fig. 1, was on the side about to descend: let us now take a particle on the side about to ascend, as in Fig. 3 (Plate XXIX). Reversing the accelerating force, as in the diagram, we get, by resolving along $a\ a$, and at right angles to it—

$$F = w \sin \theta + T \cos \phi \qquad (8)$$
$$R = w \cos \theta + T \sin \phi, \qquad (9)$$

and putting $F = R \tan \psi$, when slipping occurs as before, we get

$$w \sin \theta + T \cos \phi = (w \cos \theta + T \sin \phi) \tan \psi$$
$$\therefore \quad w \sin (\theta - \psi) = - T \cos (\phi + \psi) \qquad (10)$$

The value of θ which Equation (7) gives is less than ψ, the angle at which slipping occurs in still water, while the value of θ in Equation (10) is greater than ψ. Hence, while the inclination at which slipping takes place in the wings on the side about to descend is *less* than that corresponding with the state of rest, the inclination at which slipping takes place in the wings on the ascending side is *greater* than that corresponding with the state of rest.

To find the point of the surface $a\ a$ at which the tendency to slip is neither augmented nor decreased by the rolling, we require to make $\theta = \psi$ in Equation (7). We thus get—

$$\cos (\phi - \psi) = 0, \text{ or } \phi = \frac{\pi}{2} + \psi, \text{ or } \frac{3\pi}{2} + \psi \qquad (11)$$

If Equation (10) be treated in the same way, we shall get—

$$\cos (\phi + \psi) = 0, \text{ or } \phi = \frac{\pi}{2} - \psi, \text{ or } \frac{3\pi}{2} - \psi \qquad (12)$$

To interpret these results geometrically, draw through the axis containing G Fig. 4, (Plate XXIX.), a plane A B, making with the middle line plane an angle O G B on the one side equal to $\frac{\pi}{2} + \psi$, as in Equation (11), and making therefore an angle O G A, with the middle line plane on the other side equal to $\frac{\pi}{2} - \psi$ as in Equation (12).

The plane A B satisfies Equations (11) and (12), and we have this interesting result: that at whatever height be the free surface of the grain, that part of it lying on the upper side of its intersection with A B will shift, if the vessel be rolling in still water, at a smaller angle than when steadily inclined; the magnitude of the angle decreasing as the distance from the point of intersection increases, while that part

lying on the lower side of the intersection with A B will not slide until a greater inclination is reached than that at which it would shift if inclined in still water, the magnitude of the angle increasing as the distance from the point of intersection increases. Thus, if any line C D drawn at right angles to the middle line be assumed to be the free surface of the cargo, all surface particles lying between F and D will shift, if the vessel be rolling in still water, at a smaller angle than when steadily inclined, while all surface particles lying between C and F will not shift until a larger angle is reached. When the vessel completes her roll on the other side of the vertical, the plane $A^1 B^1$, equally inclined to the middle line plane with A B, marks the longitudinal line along the free surface at which slipping takes place when $\theta = \psi$. Hence all surface particles enclosed between the planes A B and $A^1 B^1$ below their intersection at G, as H F in Fig. 4, will exhibit a less tendency to shift when the vessel is rolling than when inclined at the same angle in still water; and since the surface at some of the sections near the ends of a vessel must often lie wholly within the planes A B and A^1 B^1 it is obvious that the same necessity does not exist for shifting boards near the ends of a vessel as amidships.

If, on the other hand, the free surface be above G, as *a a* in Fig. 4, every surface particle lying on the upper side of L, the intersection of *a a* with A B, will shift at a smaller inclination than when steadily inclined in still water, the magnitude of the angle decreasing as the distance above L increases, while any surface particle in that part of *a a* lying on the lower side of L will not shift until a larger inclination is reached. Similarly K, the intersection of *a a* with $A^1 B^1$, marks the point in *a a* at which shifting takes place at the same inclination as in still water when the vessel has rolled over to the other side. Hence, while in the case of the free surface C D, lying below G, the particles in the part H F of that surface will not slide, however the vessel be rolled, until a greater inclination is reached than that at which shifting occurs in still water; every particle in the surface *a a* lying above G will shift, either as the vessel rolls to port or to starboard, at a smaller inclination than in still water. It is obvious that if the height of the free surface be raised above the intersection of A B with the vessel's side, shifting will take place over the whole area with each roll at a smaller inclination than in still water.

The above deductions are based on the assumption, as before stated, that the vessel rolls about an axis passing through the centre of gravity. In practice, such would not usually be the case, but the amount of error involved is small, and may safely be neglected.

From the construction of Equation (7) it will be seen that the smaller the angle ϕ which the line G P makes with the middle line, the smaller will be the inclination at which slipping takes place, and hence it follows that grain with a free surface in the upper 'tween decks has a greater tendency to shift than grain in the hold.

By giving approximate values to the terms of Equation (7) we may determine the reduction in the value of the limiting angle due to rolling. Thus, if we put K = 12 ft., G Z = $1\frac{1}{2}$ ft., the ship being supposed very stiff, and $\rho = 20$ ft. for a particle in the wing in the 'tween decks, T becomes ·208 w, w being the weight of the particle. Let $\phi = 70°$ and assume ψ to be 25°. We shall get by substitution—

$$w \sin (25° - \theta) = \cdot 208\, w \cos (70° - 25°).$$
$$\therefore \sin (25° - \theta) = \cdot 1471$$
$$25° - \theta = 8° \, 28'$$
$$\theta = 16° \, 32',$$

or grain that will shift at an inclination of 25° if inclined in still water, will shift at an inclination of $16\frac{1}{2}°$ when rolling under the above conditions.

If ϕ be made 90°, and $\rho = 20$ ft. as before, we shall have a particle in the wing under the main deck, and proceeding as above $(25° - \theta) = 5° \, 3'$, or while under the assumptions, G Z being maintained the same in the two cases, grain in the wings in the 'tween decks will shift at an inclination of 16° 32′, that stowed under the main deck will not shift until an inclination of 19° 57′ is reached. The great reduction in the inclination at which shifting occurs in the wings in the 'tween decks, due to rolling, as compared with that in the wings beneath the main deck, shows how much more liable bulk grain so carried is to shift than similar cargo stowed lower down in the vessel; and in prohibiting the carriage of grain in bulk in the 'tween decks, on over-sea voyages, Parliament undoubtedly took a step in the right direction.

If the value of G Z be made 9 ins. only at the inclination at which slipping begins, in the example first given, the value of T becomes reduced to ·104 w, and substituting as before we get—

$$w \sin (25° - \theta) = \cdot 104\, w \cos (70° - 25°).$$
$$\therefore \sin 25° - \theta = \cdot 0735$$
$$25° - \theta = 4° \, 13',$$

or shifting in the 'tween decks will take place when the vessel is rolling through an angle of 21° 47′.

It is seen from these figures that the greater a vessel's stability the smaller the inclination at which shifting begins. Also, the greater a vessel's stability the greater the angle through which she rolls. Hence great stability brings about the shifting of cargoes in two ways: it causes the vessel to roll through large angles, and at the same time takes effect in reducing the inclination at which shifting occurs. Vessels laden with grain cargoes have but moderate stability as a rule, and thus the tendency is not greatly to reduce the limiting angle, if the free surface be below the main deck. On the other hand, it should be remembered that the inclining effect of a given shift of cargo is greater in the case of a vessel having little stability than in that of a stiffer vessel.

I have dealt hitherto only with the case in which the vessel has reached the limit of her roll to port or starboard, and is just about to return to the upright. If we consider the action at any point of the surface as the vessel returns, it will be seen that each particle is still being accelerated, although the acceleration is usually less than that corresponding with the extreme angle reached, and is, in addition, subject to a centrifugal force tending to push it, if it be on the upper side, still further up the hill, and, therefore, in opposition to the tendency to shift. If the particle be on the lower side, the centrifugal force increases the tendency to shift; but this cannot be so great as the tendency at the maximum inclination. The tendency to shift must usually be greatest at the limit of the roll.

Next as to heaving motion. Consider the vessel to be inclined at a definite angle θ, in still water, and given a vertical motion unaccompanied by rolling. If the vessel has reached the position of greatest immersion, and is just about to rise, a surface particle will be subject to a determinate force upwards, causing a vertical acceleration; call it P. Reversing P and resolving as before, we get—

$$F = (w + P) \sin \theta \tag{13}$$
$$R = (w + P) \cos \theta \tag{14}$$

When slipping takes place, $F = R \tan \psi$ as before, and therefore

$$(w + P) \sin \theta = (w + P) \cos \theta \tan \psi$$
$$\therefore \tan \theta = \tan \psi, \tag{15}$$

or slipping will take place at precisely the same inclination as if the vessel were steadily inclined in still water.

If the vessel be supposed to have reached the position of least immersion and is just about to descend, the value of P changes sign in the above equations, but they yield the same result as in the preceding case. We see, therefore, that the shifting of cargo is uninfluenced by heaving motion in the case considered. But the case is different if the vessel be also rolling. If the maximum immersion be supposed to be reached at the moment the vessel attains her maximum inclination, we shall have for a particle in the wing on the emerged side, using the same notation as before, and assuming that the vertical through the centre of buoyancy of the layer of additional immersion passes through the centre of gravity of the vessel, so that the value of the righting moment remains unaltered—

$$F = (w + P) \sin \theta + T \cos \phi \tag{16}$$
$$R = (w + P) \cos \theta - T \sin \phi, \tag{17}$$

and proceeding as before—

$$(w + P) \sin (\psi - \theta) = T \cos (\phi - \psi) \tag{18}$$

From this equation it appears that the decrease in the angle at which sliding begins is less than when no heaving motion exists.

Next let the vessel be supposed to have attained the position of least immersion at the moment the maximum inclination is reached. P will be reversed in the above equations, and we may write finally—

$$(w - P) \sin(\psi - \theta) = T \cos(\phi - \psi), \qquad (19)$$

or, in this case, the decrease in the angle at which sliding begins is greater than when no heaving motion exists. As an example, suppose the excess of immersion over the normal displacement to be equivalent to one-fifth of the displacement. Then $P = \frac{w}{5}$, and, as on page 366, we may write—

$$\sin(25^\circ - \theta) = \frac{5}{4}(\cdot 1471) = \cdot 1839;$$
$$\therefore\ 25^\circ - \theta = 10^\circ\ 36',$$

or sliding will take place in the case of a particle in the wing on the emerged side in the 'tween decks, under the assumed conditions, at an inclination of 14° 24′ instead of at 16° 32′, as when no heaving motion exists.

Next as regards pitching and 'scending. There is obviously no tendency to shift cargo amidships from this cause except in a longitudinal direction, and the inclination is so small comparatively that the effect of the accelerating forces and inclination combined cannot be nearly so great as in transverse rolling, except in cases where the cargo has been so trimmed that the surface assumes a tolerable slope. The resultant action would be precisely the same in character as in the case of transverse rolling. Towards the ends of the vessel, however, the accelerating forces have an effect when the vessel is also rolling similar in character to that already discussed in the case where rolling is combined with heaving motion, increasing the tendency to shift at the end about to descend, and decreasing it at the end about to ascend.

Lastly as to shocks received by blows from the sea. That vessels do receive blows from the sea, and heavy blows too, is sufficiently attested by the damage they sometimes suffer, in which the frames of erections are broken and plating indented or torn away; but it is to be doubted whether blows of the sea have any considerable effect in causing the shifting of cargo. If a vessel be inclined to port, and when so inclined be struck a heavy blow on the port side, the tendency will be of course for each surface particle to jump out of its place and roll down hill; but the mass of the laden vessel is usually so great in comparison with the blow struck, and the resistance which the water offers to lateral motion so large, that no very serious effect could in practice be experienced thereby. A blow struck on the emerged side at the moment when a vessel is about to return towards the upright will incline her still further; and thus, by increasing the inclination, and usually also the length of the righting arm, will have effect in two ways in increasing the tendency to shift the cargo.

From the foregoing it would appear that the motion of a vessel at sea does add

materially to the risk of the shifting of cargoes, and that a vessel's stability, as well as the height of the free surface of the cargo, are most important factors in determining the inclination at which shifting begins.

Another question, which I am unable now to touch upon, is as to whether grain cargoes in some cases shift bodily, except when prevented by shifting boards, as well as on the surface. The view appears to have been held at one time, by those who had given consideration to the matter, that bodily shifting did take place, because the shifting boards, which at first were carried down only a short distance below the deck, were subsequently required to be extended to the keelson.

I cannot bring this paper to a conclusion without a few words upon the subject of coal cargoes. Vessels carrying cargoes of coals are subject to no restrictions as to stowage similar to those enforced in the grain trade. No shifting boards are required to be fitted, nor is any restriction placed on the stowage of coal in the 'tween decks as in grain-laden vessels, while the surface of the coal as shipped often has a perceptible slope. In a paper on self-trimming colliers read by Mr. Denton before this Institution, in 1877, it was stated that the surface of coal assumes an angle of repose of from 32° to 38°, according to its quality and condition. From these figures it is clear in view of what has gone before, apart from the accumulated testimony of survivors from vessels that have foundered, that with an unevenly trimmed surface shifting at sea may occur at no greater inclination than in the case of grain cargoes.

It is difficult to understand why coal cargoes have been so long exempt from the restrictive legislation to which other cargoes which shift are subject. Statistics appear to show that they need it quite as much. During the three years ending 1877, 200 coal-laden British vessels foundered or were missing, and with them were lost 991 lives. During the three following years the number of vessels so lost fell to 184, and the lives to 912; but in the triennial period ending 1883 the number of vessels rose to 314, and the lives reached the melancholy total of 1,849, or more than twice as many as were lost during the same period from grain-laden vessels.

These figures indicate, I think, the necessity for some more efficient control over the loading of coal cargoes than has existed hitherto. The subject is one that has no doubt received the attention of the Royal Commission now sitting on "Loss of Life at Sea," and it is to be hoped that body will not fail to recommend some plan under which the annual loss of life resulting from the shifting of cargoes will become much reduced.

DISCUSSION.

Mr. W. John (Member of Council): I rise, Sir, to say that so far as I have been able to follow the mathematics of this paper—I have only just seen it—and from the well-known mathematical abilities of Professor Jenkins, I have not the slightest doubt that it is perfectly sound and perfectly accurate in those parts involving formulæ which Mr. Read has not read to the meeting; and I think it is an extremely valuable paper. It is a subject on which I myself have had a good deal of scientific work to do, but I have never followed it out to the extent that Professor Jenkins has in this paper. I think it will be new to all the naval architects in the meeting, in many of its features, and will be recognised as valuable. I was reminded of one thing in the early part of the paper, viz., that in which Professor Jenkins says that he had not seen any statistics about the natural slope of grain, or rather the sliding slope. I remember a good many years ago, when I was at Lloyd's Registry, we received a pamphlet from America, written by a gentleman called Mr. Mechi—I think Mr. Martell will remember it—which entered into this matter very fully, and in an original and interesting manner; and I rather want Mr. Read to ask Professor Jenkins to get those figures, as a check upon his own for the slope of grain, because it will be valuable, and I am sure Professor Jenkins would like to have them; and I daresay you, Mr. Read, will find the pamphlet in your library at Lloyd's Register somewhere about. He had not gone into the subject with the mathematical accuracy that Professor Jenkins has gone into it, but his work is valuable, and it is valuable as a record in the development of the subject. There is another very important feature in this matter of grain-shifting, as well as the slope at which it begins to slide. It is the extent to which grain will settle during a voyage, which I found a very puzzling thing to get accurately accounted for, because when you get records of ships abandoned at sea on account of the shifting of cargoes of grain, and afterwards brought in as derelicts, you find perhaps that a great deal of shifting has taken place, but the surface is uneven. The data you get in the form of evidence is such that you cannot very well get a percentage—a percentage, for instance, of settling and sinking per foot of depth—out of it; so that that is a direction also in which Mr. Jenkins might very well pursue the inquiry. A point which comes out very prominently in the paper is this: That grain near the top of a ship, grain in the between-decks, will shift when grain down below will not shift, and, therefore, I think Professor Jenkins says he commends the action of the Board of Trade in recommending shifting-boards to be put in between decks and neglecting the lower hold to some extent. Well, there are two sides to that, because in the lower hold, as a rule, you have a greater depth of grain; and, therefore, you have a greater settling; and, therefore, also it follows that you have a greater empty space between the deck and the top of the cargoes, in which a larger volume of grain can shift, and in that way the lower hold is a very important factor in the shifting of cargoes; because, unless the connection between the 'tween-decks and the lower hold is left open, as it is in some cases I know—but in others it is not—the depth of 7 ft. which you get in the 'tween-decks does not, if it has been stowed pretty well up, allow of sufficient shrinkage for the mass to shift. That is a point I wish to mention. I remember upon one occasion having to deal with a case in which it was a question whether the shifting of the cargo in the 'tween-decks or the shifting of the cargo in the lower hold had really been the source of the mischief, and the authorities in the case on the other side—there were shifting boards in the lower hold, there were none in the 'tween-decks—gave up the lower hold part of the controversy as being not worth fighting, but stuck their faith to the fact of there being no shifting-boards in the between-decks. As a matter of fact, the grain in the between-decks was so small in quantity, and could have settled so little, that it would have been impossible for any amount

of shifting there to have capsized the ship, or to have done her serious injury. But the grain in the lower hold had shifted very considerably, and had been the cause of all the mischief. I remember, too, a curious point cropping up upon which I was cross-examined pretty severely, because the opposing counsel had attached great importance to grain aloft shifting, regarding it as being of far more importance than grain below, and I had a great deal of difficulty in convincing both him and the judge that a ton of grain, or ten tons of grain, shifting at the upper deck did not produce a greater heeling effect on the ship than a ton of grain, or ten tons of grain, shifting the same distance in the lower hold. Of course, all the naval architects here know that is a matter as clear as daylight. But it was received as an absurdity at first, until I had to explain to the counsel how it was, and that he had been really trying to induce me to deny one of the elementary laws of mechanics in the matter. At that time I was conscious of the fact, and mentioned it in qualifying my replies, that, owing to the dynamical effects—I was speaking of statical effects—there would be a greater tendency, and must be a greater tendency, to shift at the upper part of the vessel than lower down, and that comes out, as one would naturally expect it to come out, in Professor Jenkins's investigations. Coal shifting I am not so sure about. I think it does not shift or settle to anything like the same extent as grain, and the statistics here given, I think, should be qualified by the fact that many of the coal-laden ships that are missing and have foundered have probably done so through spontaneous combustion and explosion, so that you have to make an allowance for that; you cannot, in fact, take statistics for grain and statistics for coal-laden ships and treat them as if they were both equally treacherous as a shifting cargo. Beyond that I can only say the paper has been of great interest to me, and I heartily thank Professor Jenkins.

Mr. B. Martell (Vice-President): My Lord, in the first place I should like to express my great thanks to Professor Jenkins, and I am sure that all the members of this Institution will likewise feel grateful that, though Mr. Jenkins has been removed from London, he has not lost interest in this Institution, but is still giving attention to the writing of valuable papers of this kind for the benefit of this Institution. This paper is of great interest, as has been stated by Mr. John, because those of us who have had to deal with this question of the losses of ships, which has been alluded to here to-day, know from the information we possess that the loss of a great proportion of the whole number of losses of ships, and of the lives of the crews in grain-laden ships, has been due to the shifting of the cargoes. There is, however, one other cause to be mentioned in connection with that, and it is a very important one indeed. We know some kinds of grain will allow a ship to be nearly filled, and where that is the case the stability of course is very much decreased as compared with cargoes of greater specific gravity; and, although a large number of these grain-laden ships have been lost through the shifting of cargo, we are convinced that what has greatly contributed to these losses has been the want of initial stability in carrying this description of homogeneous cargo which would practically fill the vessel. I think we may account to a very considerable extent for the recent diminution that has taken place in the number of losses. There has been a diminution from 111 to 74 in the last three years, and that is not due to the shifting of cargo alone, but it is also greatly due to the increased proportionate breadth of beam to depth which is now given to vessels as compared with what they had formerly. I think you must remember those two points in accounting for this diminution, although it is exceedingly gratifying to find that, in the three years since this Grain Cargoes Act has been passed, the diminution in loss has been so great as has been referred to in this paper. My friend Mr. John will, I am sure, excuse me for correcting him; but he was a little in error with regard to shifting boards. This grain Act not only required shifting boards to be fitted from deck to deck, but also from lower deck to keelson as well.

Mr. John: I was speaking of the earlier days of shifting boards. I know that is the case now, certainly.

Mr. Martell: And I think sufficient evidence has been brought forward in the experience we have had to show that grain does, in some instances, shift bodily in the hold, more particularly when shifting boards were only carried about one-third of the depth of the hold below the beams, because it is known in the experience of many nautical men that, where certain articles have been stowed down near the floor of the ship, they have been found near to the surface before the vessel got to port, showing that by the sudden motions of the ship the whole of this great mass of grain in the ship had been shifted. These investigations, from a purely scientific point of view, are very valuable indeed, because, where these results agree with practical experience, it seems to me they may also assist us in perfecting practical measures to arrive at satisfactory results. Anything that can be done in connection with this very important subject of the saving of human life and property, must be of great value to all those connected with shipping. With regard to coals, cases have occurred where coals have shifted, and the shifting of coal cargoes has caused the loss of vessels; but I quite agree with Mr. John that, in dealing with the question of losses, you cannot make a comparison as between coal-laden ships and grain-laden ships, because we must bear in mind that amongst the former are included a large number of colliers, and it is very often the case that they are the oldest vessels in existence. And no doubt some of these are lost owing to actual defects in the hull, independent of the description of cargo. At the same time, we have a very large amount of evidence to show that a great proportion of the losses of these coal-laden ships is owing to spontaneous combustion. So that it is not a fair comparison to take one with the other, or to require that, because it has been especially necessary to have an Act like that which was passed with reference to grain cargoes, a similar Act should likewise be passed for coal-laden ships. I can only again express my great satisfaction with this paper, and my thanks to Professor Jenkins for having favoured us with it.

Admiral A. F. R. De Horsey (Associate): My Lord, I should like to make a short remark to this effect: that, according to my experience, there is no such thing as an angle of repose on the high seas. The angle of repose which the table gives, from 23 degrees to 28 degrees, is no doubt very accurate, but the condition of a grain-laden ship in bad weather may be compared to holding a sieve of grain in your hand and constantly shaking it; and if you constantly shake that sieve—although you started with it at its angle of repose—I think you will find that it will have altered very considerably. I imagine that grain approaches the nature of a liquid, if I may say so; and as the ship goes over with a send to leeward, the grain gets heaped to leeward far more than is due to the angle of roll, just in the same way that water would get heaped up at the side, but, unlike water, the grain does not return. The question of securing the cargo is not sufficiently attended to, not only in grain ships but in other ships also. Of course in coal-laden ships it is of very much less importance, but it is nevertheless essential that any cargo should be protected against shifting, even a cargo of railway iron. A seaman loading a ship of which he is the owner, and which with her cargo is not insured, would take very good care that the cargo was so stowed and so secured that it could not shift in any gale of wind he might get into; but with unskilled stevedores, and fully insured ships and cargoes, the safety of the ship appears to be a matter of very secondary importance.

Mr. W. H. White (Vice-President): My Lord, as Professor Jenkins is an old pupil of mine, I take the greatest interest in all the work he does. I think Admiral De Horsey has entirely misunderstood the allusion to the "angle of repose," which is a term well-known in connection with civil

engineering; it applies to earthworks and to constructions of the kind where the material arranges itself at a definite slope.

Admiral De Horsey: I quite understood it. I only meant to imply that the motion of the ship destroys that.

Mr. White: It is the very purpose of this paper to show (first) what would be the angle of repose of cargoes in smooth water with the ship at rest, and (second) to what extent that angle would be interfered with by the rolling or pitching or heaving motion of the vessel. What Professor Jenkins has done here is to take a general equation for the rolling motion of the ship, and assuming a certain value for the extreme angle of rolling, to show how the statical angle of repose would be affected by the oscillation of the ship to that extreme angle, and by the position of the grain in the ship. He has done that in a manner which so far as I know has never been done before, putting into mathematical language and into a quantitative shape considerations which have been present to the minds of many others who have considered the subject. Many of the considerations which are here put down mathematically and given some quantitative value are those which have governed the particular arrangements to which Mr. Martell and Mr. John have alluded, but Mr. Jenkins is not content with tendencies. He tries to put numerical values on the influences of different kinds and ranges of oscillation. I quite concur in every word that has been said by Mr. Martell and Mr. John as to the value and originality in many respects of these investigations.

Mr. T. C. Read (Member): My Lord, I think that Mr. White has very clearly answered the remarks of Admiral De Horsey on the points he has raised. As Mr. White has said, the angle of repose must be obtained when the grain is perfectly at rest. It was obtained in the case of several descriptions of grain by Professor Jenkins in a warehouse in Glasgow, and he has endeavoured to find, by the method adopted in this paper, how much that angle is affected by the rolling and pitching and up and down motion of the ship when at sea. With regard to the figures quoted as to the losses of grain-laden ships, I do not think Professor Jenkins intended to convey that all these losses occurred through the shifting of grain. The causes of these losses are unknown; but, as he has shown, vessels are likely to be lost through the shifting of grain, it can fairly be assumed that a good many of them were lost from that cause. With regard to the question of fitting shifting boards for coal, Professor Jenkins is careful to point out that the angle of repose for coal varies from 32 degrees to 38 degrees. That is considerably more than the angle of repose in grain cargoes. Therefore there is not the necessity, from the point of view of this paper, to have such means taken to prevent it shifting. With reference to the remarks of Mr. John, I may say that the pamphlet he referred to, was to my knowledge in Professor Jenkins's hands when he wrote this paper, and I have no doubt that any information that had a direct bearing on the question raised in this paper has been used by him, but so far as I remember from a cursory glance through the pamphlet, it dealt more with the stability of vessels laden with grain than with the possibility of the surface part of the cargo shifting. I do not think I have anything more to say. I have great pleasure in congratulating Mr. Jenkins on the way in which his paper has been received.

The President: Gentlemen, I am sure you will allow me to convey to Mr. Jenkins an expression of your thanks for his paper. Though he is absent his heart is evidently with us, and we all remember the valuable contributions which he has made to our discussions from time to time. We are glad to know that he has been promoted lately, but we certainly regret his absence, while we thank him most heartily for his paper.

The following note on Prof. Philip Jenkins's paper "On the Shifting of Cargoes" has been communicated by Prof. A. G. Greenhill:—

"This very important practical question, which has been treated in such a very interesting manner by Prof. Jenkins, leads to some remarkable results as a problem in theoretical dynamics, so that I am encouraged to send the following note on the paper for insertion as an appendix in the Transactions of the Institution of Naval Architects.

"Referring to the diagrams (Plate XXIX.) and to the notation of the paper, the equation (3) shows that so far as the rolling motion in still water is concerned, the vessel oscillates like a pendulum of length $\frac{K^2}{G\,M} = l$, suppose, where M is the metacentre.

"The simplest practical manner of determining the length l is to observe the time of oscillation of the vessel. Thus, if the vessel makes n oscillations in a minute, the time of a roll is $\frac{60}{n}$ of a second, and, therefore

$$\frac{60}{n} = \pi \sqrt{\frac{l}{g}} \qquad \text{or} \qquad l = \frac{g}{\pi^2}\left(\frac{60}{n}\right)^2$$

"For instance, if the vessel makes $n = 12$ rolls in a minute, we shall find that l is about 80 feet.

"Now, it will be found that the result of Mr. Jenkins's calculations is to prove that the resultant of gravity W, and of the reversed effective force T at any point P, when the vessel is at the extreme inclination of a roll, is at right angles to the line P C, joining P with C, the point where the horizontal line through G then meets the line L C, drawn perpendicular to the midship line G L, when G L is made equal to l, the length of the equivalent pendulum. (The reader is requested to draw these lines, L C, G C, and P C, on Fig. 1, Plate XXIX.)

"When, therefore, the line C P makes an angle with the surface of the cargo $a\ a$ equal to the angle of repose ψ, slipping is on the point of beginning at P.

"To find, therefore, the angle of roll at which the surface of the grain cargo $a\ a$ will begin to shift, we must draw L C at right angles to G L, and then draw P C from a point in the surface $a\ a$ at the greatest distance from the medial plane of the ship, making an angle ψ, the angle of repose of the cargo, with the free surface $a\ a$. Supposing this line meets L C in C, then the angle G C L is the angle of roll at which shifting will commence, and this angle is less than ψ, the angle of repose if G is below $a\ a$, the free surface of the cargo.

"Mr. Jenkins points out that we need only consider the tendency to shift and slip at the extreme inclination of a roll of the vessel, and, as he proves, this is sufficient for practical purposes; but as an interesting theoretical problem, it may be mentioned here that in any intermediate position of the rolling, the equipotential lines of gravity and of the reversed effective forces are equiangular spirals about a certain pole or centre C, the position of C varying with the inclination of the vessel, and having the position already assigned to it when the extreme inclination is reached. The determination of the locus of C, and of the corresponding angle of the equiangular spirals of the equipotential lines, is an interesting mathematical problem in its bearing on the theory of sea-sickness, as well as of the shifting of grain and coal cargoes, which need not be further discussed here; a simple geometrical construction is easily arrived at, giving the positions of the free surface of the cargo at which slipping will commence, and confirming the theoretical conclusions arrived at by Prof. Jenkins.

ON THE PRACTICAL APPLICATION OF STABILITY CALCULATIONS.

By A. Denny, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

My object in writing this paper is twofold; first, to lay before this Institution a description of information my firm supplies to the owners of steamers we build; and second, to bring before you a simplified method of proving the stability of the steamer before she leaves port.

This information we hand to the owners, in a book which we entitle "Technical Qualities Book."

Mr. Purvis of our staff, incidentally touched upon this subject in a paper he read before this Institution in the year 1885, on "The Stowage of Steamships," but I purpose amplifying what he then said, and bringing the description up to date.

The "Technical Qualities Book" is divided into two parts:—Part i., "General Notes," and Part ii., "Special Notes and Diagrams." The first part applies to any ship, and the second part to the special ship under consideration.

These books were first produced under my late brother Mr. William Denny, in the year 1884, and although they have been amplified from time to time, very slight alteration has been made in their form.

I could not tell you in a better and more concise way our reasons for producing those books, than by quoting the opening three paragraphs of Part i.

The paragraphs are as follows:—

"Our purpose in offering these notes and diagrams to the owners of the steamers built by us, is to help them to understand and work their steamers to advantage, and to induce them to send us useful criticisms. Such criticisms will enable us to improve the various types of steamers which we build, or may be called upon to build. By means of the information now offered, we hope to give at the outset to those who have the

practical working of the steamers, a more thorough appreciation of their capabilities than they can have without it. It is possible to obtain a knowledge of such capabilities and of any peculiarities in a fairly successful way, by comparing the results of a series of voyages. But while this experience is being obtained, many mistakes may be made which might be avoided by the possession of such information as the builder can supply. Even in comparing the results of one voyage with another, it is of great advantage to start from some such definite basis as is offered in these notes and diagrams, and to have data to put a quantitative instead of only a qualitative value upon experience.

"A further use is to enable owners to compare accurately the qualities of their different steamers, so that when building new steamers they may adopt modifications from an all-round view of the question, instead of a partial one, limited for instance to two such features as speed and weight-carrying.

"The information offered in these notes and diagrams is neither so full and perfect, nor so clear and simple, as it may ultimately be made, if owners will kindly favour us with thoughtful criticism and precise information regarding the performances of their steamers under different conditions. We therefore solicit all owners to permit their captains, superintendents, and engineers, to send us without reserve their criticisms and any notes regarding their experience of the steamers supplied with this information. The very highest consideration should be given by the naval architect to information derived from experience at sea; and if hitherto it has not proved to be of much value, we believe this arises from the want of definite bases of information—such as we now offer—being supplied as starting-points from which to develop correct criticism."

The most important technical qualities of a ship are then roughly summed up under seven heads, viz.:—

(1) Deadweight capability.

(2) Speed and power.

(3) Stability.

(4) Trim.

(5) Measurement capacities.

(6) Steadiness.

(7) Strength.

Attention is drawn to an eighth quality, which is extremely important, but about which very little is known for merchant ships, viz., "turning and manœuvring power." A shipbuilder has very little opportunity of experimenting on this point, but it is pointed out to captains how very important this quality is, and they are advised to use every

opportunity of testing it. Such knowledge would prove of the utmost value to them in moments of emergency or in disputed cases of collision.

The remaining seven heads are then discussed generally in the most elementary manner possible, so that any person with a fair knowledge of arithmetic may understand the bearing of the laws which govern the various technical qualities of a steamer.

(1) Deadweight.

The meaning of displacement is explained, and also the method of constructing the common deadweight scale which every captain knows how to use.

A handy scale is given which can be applied to the common Engineers' Hydrometer, so that the captain is enabled to know what density of water his ship is floating in at any time, and how much to allow for passing from fresh, or brackish, to salt water.

(2) Speed and power.

Attention is drawn to the importance of progressive speed trials; at the same time it is pointed out, how much more valuable it would be to the owner to have his steamer tried at or near the load draught.

The method of constructing speed curves is explained, so that captains and engineers may construct such from actual practice.

Engineers are asked, if forwarding any data as to horse-power at sea, to avoid the usual practice of sending cards home taken when the engine is at its best instead of its average, which is almost invariably done in order to show a small consumption per horse-power.

(3) Stability.

This is the point I mean to deal with most fully, and it is also the point most difficult to make clear to the non-technical mind.

Instead of starting to explain initial stability, as it is usually done in text books, by explaining the term metacentre, we start by showing with simple diagrams what the difference between a capsizing and a righting moment is; and then, by the use of similar diagrams, we show that to say that a ship is under the influence of a capsizing moment is the same as to say that her centre of gravity is above the metacentre, and *vice versâ* in the case of a righting moment.

In supplying notes as to stowage and stability, the first question which cropped up was, should we supply stability curves and metacentric diagrams? We decided that such a course would only confuse non-technical men, and we therefore supply diagrams constructed with these curves as a basis, but put in such a form as to be useful for practical purposes without running risk of complexity or error.

These curves, with which I shall deal more fully later, show therefore how sufficient stability can be obtained by a judicious stowage of cargo.

We have assumed in all cases (or nearly all, for I shall mention two exceptions) the steamer stowed with a homogeneous cargo, as it would be practically impossible to have prepared diagrams such as these for heterogeneous cargoes; but at the same time these diagrams might serve as a guide to captains and stevedores in stowing such cargoes. We chose the homogeneous cargo for this reason, and also because except by carelessness a ship could not very well be more disadvantageously loaded as far as stability is concerned.

We also supply a diagram showing the different rates of stowage of different materials in tons per cubic foot, pounds per cubic foot, pounds per bushel, and the specific gravity; but for a fuller description of this diagram I would refer you to Mr. Purvis' paper.

(4) Trim, and (5) Capacity.

The notes under these heads are principally explanatory of the diagrams in the second part of the book.

(6) Steadiness.

We point out that steadiness and stiffness are very often confused with one another, although they are really opposed; that a ship which rolls a good deal is generally a stiff ship; that rolling can be diminished to some extent by winging the weights on board; but that the best means of preventing rolling as much as possible with a given ship is to so stow her that she should have as small a metacentric height as possible compatible with safety.

We have commenced working at steadiness by finding the natural period of rolling of some of our steamers in still water, but it is a subject which will take a considerable amount of work and experience before practical results will ensue.

Under this head the following words occur:—"It is desirable that much more information should be obtained than exists at the present time, connecting the stowage of a steamer with her behaviour at sea. Especially advantageous would it be to know both the behaviour of a steamer, and the metacentric height, during an encounter with bad weather."

"It is to be hoped that with a view to the above, it may in the future become common to perform an inclining experiment upon a steamer at the beginning of each of her voyages."

I think my paper will show that I have placed within the reach of captains the power of performing these inclining experiments.

(7) Strength.

We point out that our steamers are constructed under the assumption that they will never be called upon to carry cargoes distributed worse longitudinally than homogeneous cargoes. The calculations for the strength of steamers are made on the assumption of their being stowed with homogeneous cargoes of a weight sufficient, along with their bunker coal, to put them down to their load draught, and it is pointed out that when heterogeneous cargoes are carried, they should be so distributed fore and aft as to come near to the standard of a homogeneous cargo.

The General Notes conclude with an explanation of the uses of curves, with special reference to those given in the second part. This is necessary, as we find unless people are accustomed to the use of curves they are apt to be puzzled as to their meaning.

The second part of the book, entitled "Special Notes and Diagrams," refers only to the steamer under consideration, and commences with a concise table, giving the principal dimensions, length of deck erections, detailed tonnage, amount of passenger accommodation, figures relating to the sizes of machinery, draught, deadweight, &c.

I have prepared a complete set of diagrams on one half the scale, such as are supplied for a steamer, but in order to show representative specimens they are not all for the same steamer.

The first diagram, Fig. 1 (Plate XXX.), requires almost no comment, being the usual deadweight and displacement scale. The one I give is for a ship for foreign owners, and hence the scales are given both in decimetres and English feet. For the same reason the diagram does not show what we put on those for British ships, namely the Plimsoll mark. The diagram also shows a part of the midship section, with a freeboard scale, so that the captain can see at a glance what freeboard he has at any draught.

On the opposite page to the diagrams there are short explanatory notes, and an example is given of their use. After the example there is a note telling the owner or captain, should he desire to send us any information, the best form in which to do so.

Opposite the deadweight scale there is a small table showing the difference of draught due to passing from salt to fresh water at several draughts.

The second diagram, Fig. 2 (Plate XXX.), is almost as well known now as the first. It is the ordinary speed and horse-power curve obtained by means of progressive mile trials, which my late brother Mr. William Denny introduced in the year 1870. An explanatory example is given of its use, and it is shown how a very small increase in speed means a large increase in power, and hence a large increase in coal consumption.

All shipbuilders, I think, must have noticed that when an owner is comparing the performances of two steamers, the item of speed is almost always ignored, and a quarter

or even half a knot difference in speed is brushed aside as having no effect upon the coal bill.

The third diagram, Fig. 3 (Plate XXX.), is the first of its kind produced in such a complete manner. It shows at what speed the steamer should go, at any draught, with any horse power. It is constructed from data derived from our experimental tank, and although we do not put it forward as absolutely accurate, we have reason to believe that the information it gives is not far from the truth. In two cases we have had results sent us from reliable sources, which agree exactly with our curves, and in a third case I myself had the opportunity of verifying their accuracy on a sea voyage.

After the example there is a note pointing out how rapidly the speed obtained with any given horse-power falls off with increase of draught. This note is given to show owners that they must, in comparing results, not only take account of difference of speed, but also of difference of draught.

The next curves, Figs. 4, 5, and 7 (Plate XXXI.), are given to show how a steamer should be loaded with a homogeneous cargo, so as to give sufficient stability, both with coal on board and also when coal is consumed.

I give three sets of these curves, one for a steamer fitted with water ballast, and two for a single-bottomed steamer.

Take first the diagram, Fig. 4, for the double-bottomed steamer. This diagram shows at a glance for any homogeneous cargo, the weight of the cargo, what the amount of ballast should be to make the steamer safe, both with coal in and coal out, and the draught with coal in and coal out. With heavy cargoes the steamer would be at her load draught before all the cargo spaces are full, and this is shown by the rapidly descending line marked "vacant space." Even before the steamer is quite full, she begins to require ballast for a homogeneous cargo.

You will notice that the ballast curve for coal in, which descends rapidly after a stowage of 54 cubic feet per ton is attained, rises suddenly again at 68 cubic feet; this occurs because all these diagrams are made under the assumption that the steamer shall never have less than ·8 of a foot metacentric height, and ·8 of a foot righting arm at 30° and 45° inclination. Up to 68 cubic feet the righting arm condition governs this case, but after that the metacentric height governs, and hence the sudden break in the curve.

We decided upon these limits of stability after a great deal of consideration, and after consultation with various people; but one of the principal objects of my paper will have been attained if it serves to provoke discussion and elicit information upon this very important point. The information bearing upon this point is meagre at present, and will remain so until it becomes the practice to incline steamers before proceeding to sea, and thus find out what metacentric height is found to be safe in practice.

At this point I would like to acknowledge the assistance we received in 1884 from Mr. Martell, who placed at our disposal the results of his experience.

Proceeding now to the consideration of the two, or rather three diagrams, Figs. 5, 6, and 7, for the single-bottomed steamer: Fig. 5 shows the cargo weight and the draught with coal in and coal out, for any rate of stowage, and also gives a curve of vacant space necessary to provide for sufficient stability in the worst condition, which may either be before or after the coal is consumed.

As it will be generally advisable, for purposes of trim, to leave the vacant space forward, Fig. 6 is supplied, showing the forward limit of the cargo in the upper 'tween decks.

Fig. 7 shows how a full cargo may be carried by the use of ballast. It is similar to Fig. 5 in every respect, except that a curve of ballast takes the place of the vacant space curve.

By means of these two diagrams (Figs. 6 and 7) an owner can decide whether it will pay him better to ship ballast or leave vacant space. For example: suppose the steamer to carry a cargo of tea stowing 90 cubic feet to the ton; then the cargo weight would be 2,900 tons, and the draught with coal in would be 22 ft. 3 in. If instead of shipping ballast, vacant space was left, then the cargo weight would be 2,650 tons, and the draught 20 ft. 11 in.

This comparison may be made to include the element of speed as read from Fig. 3. Supposing the I.H.P. developed in each case to be 3,000; then the speed with ballast on board would be 13·1 knots, and with vacant space 13·3 knots. The owner having thus full information before him, can decide as to the most paying way of working his steamer.

In two cases we found it unnecessary to supply these stability diagrams, as the steamers could carry any homogeneous cargo without the use of ballast or vacant space. In both these cases the upper 'tween decks were fitted with passenger accommodation.

In other two cases, when we happened to know that the steamers would carry in certain fixed portions of their holds cargo of a known density, and also that there were optional methods of stowing the coal, we supplied as well as the diagrams, tabulated information of the same nature as that given by the curves for four different methods of stowing cargo and coal. We supplied this information tabulated, in order to avoid multiplying diagrams.

Fig. 8 (Plate XXXII.) shows the trim of the steamer when fully loaded with homogeneous cargoes of different densities. No consideration is given in it to the use of ballast, but if from the stability diagram it is known that ballast is required, the trim diagram helps to indicate the position, in the fore and aft direction, where

this ballast should be placed. The next diagram to be described, Fig. 9 (Plate XXXII.), is required for this purpose. Fig. 8 also shows the immersion or emersion of the propeller blade tips.

Fig. 9 in form resembles the first, and is a scale showing the moment in foot tons to change the trim one inch, and also the tons per inch immersion at any draught. For purposes of practical calculation it is not very wrong to consider the approximate longitudinal centre of all water planes to be the same, and hence we give the distance of this centre, about which trimming moments are to be taken, from the rudder-post. This diagram is used in conjunction with the last diagram in the book, which is a longitudinal section of the steamer, in calculating alterations of trim, caused by adding or removing weights, or by shifting weights already on board.

Fig. 10 (Plate XXXII.) is a longitudinal section of the steamer, and gives a large amount of useful information, such as the cubic contents of all holds and the vertical and longitudinal position of their centres of gravity, contents in tons, of bunkers and water-ballast compartments, and the position of their centres of gravity, and the amount of fresh water in gallons, &c.

This completes the description of the contents of the "Technical Qualities Book." Perhaps in my endeavours to condense I have not made everything clear, but the limits of my paper do not admit of more space being devoted to its description.

We have produced these books for seventeen steamers, including sister ships.

At first we did not receive very much encouragement, but latterly we have received some very useful communications, one of which I shall read in extract. This communication was received from the captain of a large steamer we built for the Colonial trade:—

"The second diagram I have found very useful and accurate, and when used in conjunction with the third diagram, I find the speed, allowing for the draught of the ship, and the power exerted, a very good guide as to the number of revolutions I want to drive and the quantity of coal consumed. If anything, in ordinary weather when in good trim and the coals of good quality, we do a little better than the diagram shows; but at sea it is not easy to get a smooth day. . . .

"Referring to the scale for moment to change trim 1 in. and calculating the amount of coal, fresh water, and stores used, you can come very near the draught; and this I find of great service when you want the draught as near as possible for a place short of water. I find I can get the draught within a couple of inches by doing so, and by pumping out or filling up forward or after ballast tank, alter to the trim as required, finding by the diagram how much each tank will affect the ship, and in what way. I tried the ballast tanks in harbour, and found the trim alter as per diagram. The

stability diagram I cannot quite make out, but no doubt it is more my fault than the fault of the diagram. . . .

"There was not enough water to get out of the harbour without pumping out some of the ballast, and I had pumped out No. 6 and 7 tanks, and did not like to pump out any more, as we had a great deal of weight in the between decks. . . . What I could not make out from your book was this question: 'Was it safe to pump out any more water with so much weight so high up?' I thought not. It would be useful to know another time, as we are always being stuck up at this port for want of water, and we have constantly to carry weight high up. The ship on getting to sea appeared to be stiff enough, but rolled a good deal. I had however to run up No. 6 and 7 tanks, but as the coal was worked out of the 'tween decks I pumped them out again, and then we rolled less. I think the ship did very well in some heavy weather with a very high beam sea. . . .

"The first part of your book, which I have carefully read with much interest, contains much practical and useful information, and the diagram showing the space occupied by various kinds of cargo cannot fail to be appreciated by masters, as giving them a correct idea of what amount of cargo their ships will stow with different kinds of goods. . . .

"I wanted to have sent you this time the time we took to turn right round, both on the port and starboard helm, at full and half speed, but could not get a calm and smooth day. Any wind or sea affects a long ship so much in turning, that unless you know the force of the wind, and what sort of sea there was, the results are useless."

The receipt of this report, as you can well understand, cheered us very much, and encouraged us to proceed in supplying this information.

The remarks made by this captain as to the difficulty he had in understanding and applying the stability diagrams led me to reflect as to whether it was not possible to so simplify the process of inclining, and also the calculating work involved, as to render it possible for a man untrained in stability work to perform the experiment. I well know that no amount of simplification in apparatus or calculation can ever do away with the great care needed in performing the experiment, but I have always thought that the experimental part could be performed after very little practice, by any careful and thoughtful man.

This idea has been proved correct; the experiment has been performed successfully by the Superintendent-Captain of a large company, for which we have constructed many steamers. We have verified his result by comparing it with our original inclining experiment, and find the two to agree within limits sufficiently close.

My first idea was to supply the captain with a simply constructed pendulum fitted with a scale, by means of which he might read the inclination in inches at a given distance from the point of suspension; and to supply a curve constructed under our conditions of stability, with draughts as abscissæ and these readings as ordinates; the inclining moment being a constant.

I at once saw that I could render the diagram much more useful for double-bottomed steamers, by adding other curves showing what amount of water ballast should be pumped out or run in, at any draught, for any inclination less or greater than the inclination which indicates safety.

My idea was very skilfully worked out by Mr. John Nicholson, a member of our staff, and the author of the paper on "The Method of Arranging the Coal Bunkers of a steamer so as to Reduce the Ballast to a Minimum," read before this Institution in 1885, who hit upon the idea of combining the diagram and pendulum.

Fig. 10A (Plate XXXII.) shows how the combination is effected in the apparatus we supply. The pendulum consists of a round disc of iron, having attached to it a thin wood baton, the working edge of which is in a line with the knife edge. This knife edge is attached to a flat iron rod about 6 feet long, fastened to the top of which is a wooden board parallel to the plane of the iron disc, and so arranged that the back of the wooden baton just clears its face. To the back of this board is attached a brass slotted quadrant, and two screw nails passing through the slots serve to attach the instrument to any transverse bulkhead; at the same time the quadrant gives a certain latitude of adjustment for initial list in the steamer.

On the wooden board is pasted one of the diagrams to be described, so that the others may be fixed in the correct position when an observation is to be made. The middle vertical line, and one of the horizontal lines of the diagram, are produced beyond the limits of the paper, to serve as guides in correctly affixing the observing diagram.

As it is necessary that the inclining moment should always be exactly the same, the diagram being constructed on this supposition, and as it is also desirable that the inclining weights should be easily shifted, we decided after consultation with a captain of one of our steamers, that the best way to ensure a constant moment and an easily handled weight would be to fill one or more of the ship's boats with water, while resting in their chocks. In practice, for a steamer of about 5,000 tons gross, it was found sufficient to use two 30-feet life-boats on each side; this gave an inclining moment to either side of about 224 foot tons.

It having been decided to perform an inclining experiment, the captain rigs up his pendulum and affixes his diagram to the board. He then sees that all his moorings are slack, all gangways, barges, &c., free of his ship, and finally—and this is the most

important condition—that there is no free water in the bottom or bilges of the ship. He then, unless the initial list is serious—say more than 2° or 3°,—adjusts the pendulum frame by means of the quadrant until the wooden baton coincides with the middle vertical line on the diagram. The boats are filled on the one side, and the point to which the baton moves on the board is marked on a horizontal line corresponding to the mean draught of the steamer; the boats are then emptied on the one side and filled on the other, and the point to which the pendulum moves again marked; finally, the boats are emptied, and it is observed whether the pendulum comes back to the vertical, as of course it should. During the whole of the inclining experiment no moving of weights or pumping operations must be allowed, and if many people are on board they should be instructed to remain still and in the same place all the time.

We have performed this operation with those diagrams in the case of two steamers leaving London.

In the first case the steamer was fitted with water ballast, and it was found that 300 tons of this ballast could have been removed with safety. The captain however, from reasons altogether apart from stability, preferred to retain the ballast; had it been otherwise, and the ballast been removed, a distinct gain in the economy of working the steamer would have resulted. This steamer, when inclined, had a metacentric height of 1·45 ft., and has since completed her voyage to the colonies successfully. The diagram we anticipate will be of greater use in the case of this steamer for her homeward voyage, when the cargo is of a peculiar nature, and is stowed in such a way as to necessitate a large use of water ballast.

The second steamer was a single-bottomed one, and when inclined it was found that she could have taken about 800 tons of cargo in her 'tween decks. As she was carrying emigrants to the Colonies, it was not possible to ship this cargo; but I have no doubt that as a result of the experiment this steamer, under similar conditions, will be so stowed as to reduce the metacentric height. It was in this case 2·54 ft., which I am inclined to consider excessive; but as her voyage is not yet completed, we have no definite information of her behaviour at sea.

Of Figs. 11 to 18 (Plates XXXIII. and XXXIV.), eight in number, four are reductions of diagrams we have actually supplied for three steamers built by us.

All the diagrams are constructed upon the assumption that a steamer never has, in any case, less than ·8 of a foot metacentric height and ·8 of a foot righting arm at 30° and 45°.

Referring to Fig. 11, you will see that there is a middle vertical line, also equi-distant horizontal lines which represent draught, and are numbered accordingly. On either side of the vertical line there is a series of curves; the heavy black one

marked O is what I call the safe curve, and the others on either side of this curve are numbered 100, 200, &c., the meaning of which will appear immediately.

Suppose now that your steamer is at any mean draught, say 24 ft., and that she is inclined by the constant moment; if the pendulum moves out until it cuts the horizontal line marked 24 at its intersection with the curve marked O, you know that the steamer is safe. If instead of this the pendulum moves out until it cuts the curve on the outside of the safe line marked 200, you should remove 200 tons from the upper 'tween decks; if, on the other hand, the pendulum only moves out to the curve 200 inside the safe line, then you can add 200 tons to the upper 'tween decks with safety; that is, provided you are not already at the load draught.

This diagram is for a single-bottomed steamer, and the great use of it is that the captain can incline his steamer before arriving at the load draught, and find out how much, if any, cargo he can add to the upper 'tween decks.

Fig. 12 is for the same steamer, but as there are two ways of stowing the coal, one of which causes increase and the other decrease of stability as the coal is burned, we were obliged to provide two diagrams, the safe line in the case of the decreasing stability being so drawn that the steamer would be safe when the coal was consumed.

Turning now to Fig. 13, which is the case of a steamer fitted with water ballast, you have as before the safe line; the other curves, numbered 100, 200, &c., show how much water ballast must be pumped out or run in for correct stability.

Fig. 14 is also for a double-bottomed steamer. The other two steamers had large freeboard and long water-tight superstructures, and hence their stability was always governed by the ·8 of a foot metacentric height condition; but in this case the steamer having low freeboard, at a draught of about 20 ft. 9 in. she comes under the other condition, of ·8 of a foot righting arm at 30°, and to obtain this it is necessary to increase the metacentric height; this as you see, has a curious effect upon the safe curve and the other curves, tending them inwards. This change of direction was to be expected.

We only commenced the construction of these diagrams within the last four months, and the first ones were all prepared more or less in a hurry, in order that they might be sent off with the steamers to which they belonged; but within the last month we have been able to further improve them, and Figs. 15 to 18, show these improvements. I look for still greater advances in this work, which I hope to communicate to this Institution at a later date.

In the case of a single-bottomed steamer our original diagram permits of inclining before the steamer has reached her load draught; it would then show whether any cargo

could be added to the upper 'tween decks, and if so, how much. But this was not the case with the double-bottomed steamers. If the steamer was at her load draught and the inclining experiment showed that water ballast should be added, the draught would prevent the addition. Hence we have seen reason to add to these diagrams 'tween deck cargo curves similar to those for single-bottomed steamers. These are shown in dotted lines on Fig. 15.

Another development is shown on Fig. 16, where cross curves are introduced. The diagram is for a steamer not provided with water ballast, and the cross curves are constructed through the points of intersection of horizonal lines representing increments of draught for increments of 100 tons displacement (in the form of cargo), with the corresponding curves of cargo to be put in or taken out of the 'tween decks. They are to be used as follows :—Suppose that the captain inclines his steamer when she is at 22 feet, and his pendulum moves out until it cuts the cross curve A at its intersection with line 22, he knows at once that he can add at least 1,400 tons to his 'tween decks, and that his steamer will then be at 25 feet mean draught, that is to say, will be at the draught where the cross curve cuts the safe line. Again, suppose his pendulum moved to the intersection of cross curve B, then he could add about 440 tons, and his draught would be 23 feet.

Fig. 17 gives analogous cross curves for a water-ballast steamer; the difference being that the intersections with the curves of ballast are obtained by setting off decrements of draught for decrements of 100 tons displacement (the decrements being in this case brought about by removal of water ballast).

A further extension of these cross curves, and I think a very pretty application of them, is as follows (see Fig. 18) :—Suppose the steamer is at 22 ft. draught, and when she is inclined it is found that the pendulum moves out on the draught line to its intersection with cross curve A, then 900 tons of cargo could be added to the 'tween decks, and by following up the cross curve to its intersection with the safe line, it is found that the steamer would be at a draught of 24 ft. But her load draught is 24 ft. 8 in., and it would be impossible to add more cargo to the 'tween decks without adding water ballast; the problem then is: How much water ballast should be run in, and how much cargo is it possible to put in the 'tween decks? Take the cross curve for water ballast to be run in which cuts the safe line at its intersection with the load-draught line, and here it is seen at once that if sufficient cargo (about 200 tons) was added to immerse the boat to the draught corresponding to the intersection of the cargo cross curve A with the ballast cross curve B, then the want of stability caused by this addition could be corrected by adding sufficient water ballast (about 70 tons) to put her to her load draught.

In conclusion I would say, that I do not intend or suppose that those diagrams will

supersede or in any way decrease the value of the stability diagrams supplied in the "Technical Qualities Book," but I feel sure that they will complete the book in so far, that while the diagrams given therein were only directly useful for homogeneous cargoes, those diagrams will specially apply to heterogeneous cargoes. Those diagrams have the same end in view as the "Technical Qualities Book," namely, to supply to owners and captains a royal and rapid road to a perfect knowledge of their steamer. I do not suppose that after the first few voyages they would be used, save in exceptional cases of loading.

I am not the first who has attempted to simplify the method of inclining steamers. Mr. Taylor read a paper before this Institution, in the year 1884, on a "Stability Indicator" devised by himself, the arrangements in connection with which were very complete; but he intended that the captains should use and be acquainted with metacentric diagrams and stability curves, which we on the other hand, and I think wisely, have endeavoured to avoid. I sincerely trust that the Admiralty will, as I believe they are contemplating, take the lead, and insist that all steamers employed for trooping and other Government purposes, shall be inclined before proceeding on their voyages. I feel sure it only wants a beginning, and that when owners and captains find that there is so little trouble and expense involved, that inclining experiments will become as much the rule as they are now the exception.

DISCUSSION.

Sir Nathaniel Barnaby (Vice-President): I remember, my Lord, when twenty years ago the members of this Institution in council did their best to try and devise some means by which those in command of merchant ships might know before they started on a voyage what the behaviour of their ship in respect to stability was likely to be; and I think that in our Transactions for the year 1867—just twenty years ago—may be seen what was the result of our deliberations. I suppose it was not a wise conclusion that we came to as to indicating the way in which it might be done. I suppose it was not wise because, as a matter of fact, it has never been taken up by the owners and captains of ships. Having waited for these twenty years, I am sure we shall all of us be rejoiced to have put before us in this simple and effective way what has in it great promise. One wishes that our old friend, whose name has been mentioned in connection with it, were here this morning, that we might congratulate him on the good work done by his firm; and I am sure that the fact that the younger member of the firm has had so much to do with what we have seen here, and have been so pleased to see, must be a source of great gratification to us as an Institution, and we may hope that the name of the firm will continue to be held by us in high honour.

Mr. W. John (Member of Council): My Lord, I can only say that when I heard this paper read I felt that it was conceived in the broad and liberal spirit in which the late William Denny always gave out information to the world through this and similar Institutions; and that the spirit of him, whom we all lament so much, runs through the younger members of the firm; and I think that is a

circumstance that we may congratulate ourselves and the profession upon. The paper itself is a very valuable paper. The suggestion is a good one. It has a taking simplicity about it for the captain of a ship. I believe the recommendation made by this Council twenty years ago, to which Sir Nathaniel Barnaby has alluded, was one for taking the time of the oscillations of ships before leaving dock in a loaded condition. It had this disadvantage about it, that it could only be done just before leaving dock, when the cargo was in the ship and was stowed for good and all; and unless it turned out that she was excessively tender, which would have showed itself in the stowage of the ship, nothing would have induced the captain to delay the ship by taking out the cargo and re-stowing it. The present proposal is a practical but tentative process by which an intelligent captain, or, if he is not there himself, his chief officer, can find out occasionally how the stowage of the ship is going on, and find out in time how to check any tendencies towards excessive stability or instability. It is the most hopeful thing of the kind that I have seen. For that reason I must say I am pleased with it, and hope to see it in use, and I think it will come into use.

Mr. B. Martell (Vice-President): My Lord, I think after what has been said, that perhaps nothing more can be said on this subject in the way of congratulation to Mr. Archibald Denny for the ability he has shown in preparing this paper, were it not that I think it would be gratifying to him to know his labours were appreciated. I know his desire in writing it, that he should be informed of the opinions entertained by the members of this Institution, and I can only echo the words of Mr. John, that we have cause to be thankful in finding that though we are deprived of our late lamented colleague, Mr. William Denny, we may look forward to his loss being to so great an extent supplied by his energetic younger brother. The firm of Messrs. W. Denny & Brothers have always been so ready, so generous, and so frank in giving all possible information to the world, and have shown such an exemplary pattern to other shipbuilders, that I am sure we should be wrong not to express our appreciation of their conduct in the highest terms, and it is, I am sure, a source of great gratification to all of us to find, that this policy is so thoroughly endorsed by the younger branches of the firm. Now, this paper seems, I think, to supply what we have been looking for for some years. We all know the great value of reliable data of this kind to guide us in the consideration of the great and important question of the stability of mercantile ships. As I said only a short time ago, we know the great number of losses that have been due to the want of stability in ships, and to the improper loading of ships, occurring in many cases through the captain not properly understanding the properties of his ship, and knowing what he could do with certain cargoes and what he could not do. At Lloyd's Registry some time ago we endeavoured to do what we could in this matter, by inducing the owners of comparatively narrow ships, where we felt when loaded with homogeneous cargoes they would be very unsafe from want of stability if the cargo shifted a little, to incline their ships in order to ascertain the correct position of the centre of gravity. We then gave them practical information for ascertaining what amount of cargo they should leave out between decks, or what amount of water-ballast they should run up so as to ensure a fair amount of stability. That applied to homogeneous cargoes—cargoes of one description only. But here we are supplied with a plan applicable to any kind of cargo that it may be intended to take on board a vessel, and, as Mr. John said, we shall not have to wait until the loading of the ship is completed; but an intelligent captain can gain this information and see what cargo he can put in, how much more, and where he can stow it, so as to ensure a reasonable amount of stability for his ship. As you know, a long discussion took place in this room with reference to the suggestion that curves of stability should be placed in the hands of captains to guide them with reference to the stability of their ships; but it was also felt that it would be very unfair to the captains to saddle them with the responsibility of having to apply

these curves of stability, because it would require a considerable amount of mathematical knowledge to know at a pinch how it was necessary to apply them, and that it would really be safe to leave them to their practical experience rather than to expect them to apply curves of stability of which they could know so little. But here we have a system which is founded on accurate scientific information, and affords a practical means of arriving at useful results of this kind. In order to use it a captain need not understand the actual nature or calculations of stability curves, but by taking this simple arrangement he can, whilst loading, arrive at an accurate knowledge of the condition of his ship. I cannot help thinking, seeing how easily this can be done by an intelligent man, and the very small expense attending it, that it will come into general use, and will be very highly appreciated, and result in very much good. I have only in conclusion, my Lord, to congratulate Mr. Archibald Denny on having placed such a valuable paper before us.

Mr. L. Benjamin (Member): My Lord, it is not in my power to express in as dignified words as those of the gentlemen who have spoken before me my regret for the sad cause which has prevented Mr. Archibald Denny from being present, and I shall, therefore, with your Lordship's permission, proceed to the subject without further preface. What Mr. Martell has just now said with regard to the value of giving stability curves to shipowners I fully agree with, and I share the admiration for the completeness of information contained in the diagrams of this paper; but I am afraid that if you were to give owners and captains curves like those in the Qualities Book, or like those exhibited on the wall diagrams, they would have just as much—and perhaps more—difficulty in understanding them than if you were to give them a simple curve of stability. Not that I am going to advocate that captains should be supplied with stability curves; but what I mean to say is, that these would not confuse them more than a book would which has so many curves in it as that one which is laid before us in this paper. Even a naval architect would find some difficulty in grasping, after a short explanation, the exact meaning of these diagrams—say, for example, of the diagram (Plate XXXII.) just in front of me. And, moreover, although you may have understood their meaning fully at the time of the explanation, if after some time you have them brought before you again, you would have to study them thoroughly before you could make any use of them. How much more will this be the case with captains whose education is not a mathematical one? These ideas have been very often forced upon me, and, I daresay, upon many others who have had to supply captains with theoretical information; and I have come to the conclusion that it is not advisable to give a captain or a shipowner any curves or diagrams whatever. What I propose to do, and actually have done, for the purpose of making practical use of stability calculations, is the following: I give a table containing figures only, and only such figures as will be distinct to captains at the first glance. The data contained in that table are the following: For certain conditions of loading I give for each vessel (besides the draught and the displacement)—Firstly, the height of the metacentre above the centre of gravity. I know that some gentlemen will object to giving captains anything connected with the word "metacentre," but there is no need to use that word. Well, in the first column of the table I give the metacentric height for certain conditions. Secondly, I give a column of the vanishing angles of positive stability for the same conditions of loading; and thirdly, the maximum righting arm which occurs in the interval between the upright position and the vanishing angle for each of these conditions. According as to whether these three items are small or large, the vessel is unstable or stable, and remarks to that effect are added in another column provided for that purpose. It will not require much knowledge or trouble to learn to draw conclusions from the comparative values of these data. The conditions of loading for which I give these data are the following. Firstly, I assume the whole vessel to be filled with homogeneous cargoes of different densities—say 40, 50, and 60 cubic feet to

the ton respectively. Secondly, only certain holds to be filled with cargoes of the same description. Thirdly, the lower holds filled with a heavy homogeneous cargo and the upper hold with a lighter one. Fourthly, the reverse case, *i.e.*, the lighter homogeneous cargo below and the heavier one above. Fifthly, for those of the above conditions of stowage where it appears necessary, I show the modifications of the data in the three columns due to the filling of water ballast, the emptying of the coal bunkers, &c. All this information can be placed together in a list of very small compass, which would not fill more than a sheet of foolscap, and which comprises every information which the commander of a merchant vessel may want, as he can easily bring any load he may have to deal with under one of the given classifications. And I believe that the information in this form will be easier understood by practical captains than if they had curves and diagrams to deal with. As I have read a paper on that subject in Liverpool, which was reprinted in full in *Engineering*, in December last, I may refer to that paper for further explanation. I shall, with your lordship's permission, refer to another point of the paper. Mr. Denny says he has worked on the assumption that it is necessary to have a metacentric height of ·8 ft., and righting arm of the same amount at 30° and 45° inclination. A reason for fixing these minima is not given. I cannot agree with the idea, and have never been able to see how you can fix a mimimum value for metacentric height, or for the righting arms, which should hold good for all vessels. Am I right in assuming that the meaning of this sentence is, that these minima must be ·8 ft. for any kind of vessel whatever? Well, then, there are certain classes of vessels which would be altogether unsafe if they had only that amount; and, again, there are other classes of vessels which would actually require no positive metacentric height at all, and which would still be safe. I don't think that one can state in such a broad manner that a certain metacentric height would be sufficient for all vessels. Some years ago Mr. MacFarlane Gray compared, in this Institution, a ship to a common cradle, for the purpose of giving a popular explanation of the meaning of the term "metacentre." Let us take the case of two cradles, a large one and a small one, and it will not require much thought to find out, that what corresponds in the cradle with the metacentre in the ship must be in different conditions in the two different cradles. That holds good for ships also. With regard to Mr. Taylor's Stability Indicator, I do not think that this would offer great difficulties to captains, and it would be quite as easy to use that instrument, with the aid of a simple curve of stability, as the one exhibited here with the encumbrance of all these complicated diagrams. I may add that the remarks which I have made are by no means intended to express my doubt of the usefulness of the substance of this paper; on the contrary, I most emphatically express it to be my opinion that the paper is of very great value to the naval architect; but what my remarks aimed at is, that the use of these diagrams should be confined to the office of the naval architect, and that the captain should get more comprehensible information into his hands, which would form, as it were, an extract from the curves and diagrams.

Mr. J. H. Heck (Member): My Lord, I would just like to make a few remarks which I think will bear upon this question. I have read the paper with much pleasure. In my opinion it is a very valuable one, as hitherto there has been an idea—in fact one, I believe, expressed at the meeting to-day—that shipowners were really not paying attention to the information which stability calculations afford. So far as my experience goes, judging from the various conversations which I have had with a number of shipowners, I find that they would be quite willing to adopt any simple and cheap arrangement, such as is suggested in this paper, for finding the centre of gravity of the vessel when loaded, provided shipbuilders would only show them how, and in what way, it can be done. The point I like best in the paper is the fact, that it marks the beginning of a practice by an eminent firm of shipbuilders (which I hope will be followed by others) of giving much valuable and necessary

information to shipowners, so as to enable them and their captains to know and judge how their vessels should be properly stowed. The general adoption of some such plan would, I feel sure, tend very much to increase the safety of vessels, and to the reduction of loss of life at sea.

Mr. F. P. Purvis (Member): My Lord, I think the only thing which I have to reply to is one remark of Mr. Benjamin's. He spoke about the complexity of these diagrams. If he will read the paper he will find that the only diagrams yet given to captains of steamers are those shown in Figures 11, 12, 13 and 14 (Plate XXXIII.). I think a captain who has had the first of these, and used it for a couple of voyages, would then say to himself, What further use can I get out of this diagram? It shows me whether the ship is safe or not, but I want to know something more. I want to know what I am to do, when she is not safe, towards putting her safe. I want to incline her before she gets to the load line, and know what to do next." Then he would come to us and ask us for something more, and then the diagram represented by Fig. 18 (Plate XXXIV.) would be ready for him. The remarks which have fallen from so many of the members complimentary to Mr. Denny I shall be most happy to communicate to him.

The President: Gentlemen, I hope you will allow me to say this much, that I am perfectly sure that the appreciative observations, the compliments paid, and the thanks that have been expressed to Mr. Archibald Denny, will be a reward to him for the labour he has bestowed on this very valuable paper, and, I may add, I am sure that the kind and sympathetic remarks which have fallen from so many speakers will be equally acceptable, and, I hope, a source of comfort to his grieving family at this time. I am sure you will allow me, in his absence, to convey our united thanks to Mr. Archibald Denny.

ON THE PRINCIPLE OF AN HYDRAULIC APPARATUS FOR TRANSMITTING SIGNALS AND POWER, AND CONTROLLING ALL SORTS OF DISTANT MECHANISM.

Paper communicated by Mons. E. Widmann, Member, and Mons. Marc Berrier-Fontaine, Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887 ; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

Conjointly with Monsieur Marc Berrier Fontaine I beg the honour to submit to the Institution the principle of an hydraulic apparatus for transmitting signals and power, and for controlling distant mechanism, which we thought out together while we were engaged at the Arsenal of Toulon, and which appears to us to be susceptible of numerous applications on board ships of war.

This principle is none other than that of the transmission of pressure in a fluid mass in equilibrium. Suppose two cylinders to be filled with water, and to be connected by a pipe of any length and diameter. If we vary the interior pressure in one of the cylinders, the same variation will be produced in the other. If then we fit into each cylinder a piston, surmounted by a spring, so as to form a sort of pressure gauge, similar to a Watts' indicator, the oscillations produced on either spring by the variations of the pressure will be identical. If we regulate these variations at pleasure, so as to bring the spring of the first cylinder, which we may call the "manipulator," to any given point, the spring of the other cylinder, which we may call the "repeater," will take up the corresponding position, and that, too, no matter what may be the distances apart of the two cylinders, or the form of the connecting pipe. There is a very simple method of varying the pressure in the manipulator, on vessels provided with a system of water under pressure. All that is required is to put this cylinder into communication with the pressure pipe ; for example, with the return pipe, by means of a "distribution box" similar to that employed by Sir William Armstrong and Mr. R. Tweddell ; if, then, the lever which governs this box is joined to the spring, by means of the system of link-work with double centres, invented by Mr. MacFarlane Gray, it will be possible to bring the spring of the manipulator into any position whatever, as determined by the position which it was thought proper to give to the lever of the distribution box.

At the other end of the pipe the spring of the repeater reproduces the movement of that of the manipulator, and actuates the distribution box of the principal apparatus, by means of a system of link-work, which renders the movements of this apparatus absolutely identical with those of the springs, and, consequently, with those of the lever on which the hand of the operator acts.

In our opinion this hydraulic apparatus is susceptible, amongst other applications, of being used to work the rudder. In this case it would have the advantage of not requiring any mechanical means of communication between the bridge and the rudder, which would get rid of a difficulty well known by all who have had to provide for mechanical transmissions of this nature on our large war-ships, whenever it is desirable to be able to steer from the fore part of the vessel, or even from the top.

The manipulator, Fig. 1 (Plate XXXV.), is fixed at any convenient place on the ship; on the bridge, in the conning tower, or even on the "top," under the hand of the helmsman and within reach of the orders of the captain.

The repeater, Fig. 2 (Plate XXXV.), is placed in the neighbourhood of the apparatus which has to be actuated or governed, and which may be, according to circumstances, the steering engine, the engine which moves the turrets or the guns, or even the main engines.

The manipulator and the repeater are connected by means of a pipe J J′ of any section and length which can be conveniently got into the most protected parts of the ship, and which may be made to turn all obstacles due to the internal arrangements, and to pass through watertight bulkheads without any difficulty. The apparatus is supposed to be fitted on board a ship provided with a service of water under pressure, including an hydraulic accumulator, and a main C and return pipe R.

The distribution box S of the manipulator contains two valves. When one of these valves is raised the water under pressure finds its way into the cylinder of the manipulator through the pipe H, causing the pressure in the cylinder to rise and compressing the spring. On the other hand, when the other valve is raised, the interior of the cylinder is put in communication with the general return pipe, R; then the pressure in the cylinder diminishes and the spring is extended.

In order to bring about at will either of these inverse effects, the hand of the operator acts on the distribution box by means of the system of levers and link-work L N T U, which is arranged in such a manner that the movements of the piston or of the spring are identical with those of the hand lever. When the latter is moved in such a way as to open the valve which permits the water under pressure to enter the cylinder, the piston commences to move, but its motion causes the opening worked by the valve to be closed,

in such a manner that the piston stops in a position which closes the distribution box both to the pressure and the return pipes. In other words, the line got by prolonging cU, should always pass through the point O, which corresponds with the closing of the distribution box, *i.e.*, with the position of equilibrium.

When, then, the hand of the operator causes the lever to move over the sector X Y, the piston will pass over the distance c′c″, and its movement will always be fixed and under control.

On the other hand, if from any cause the pressure in the pipe were to be lowered, the spring would distend slightly, and the effect of its movement would be to re-open the valve of the distribution box and to re-establish the pressure.

Let us now consider the other extremity of the pipe J J′. The piston of the repeater reproduces all the movements which may be given to the piston of the manipulator This piston of the repeater is connected with the distribution valve of the apparatus which has to be actuated (rudder, turrets, guns, &c.) by means of a system of link-work similar to that which has been already described, and so arranged as to compel the apparatus in question to take movements corresponding to those of the piston of the repeater.

What will be the net result of this combination ?

1. The hand of the operator regulates the movements of the spring and piston of the manipulator.

2. The spring belonging to the repeater at the other end of the pipe moves identically with the piston of the manipulator.

3. The apparatus to be actuated is compelled to conform absolutely to the movements of the repeater.

The final result, then, is the same as if the operator had the distant apparatus directly under his hands.

Plate XXXVI. represents an arrangement applicable to the working of a rudder for a vessel having a rounded stern. The tiller, which may be very short, passes through a bronze crosshead working in a forged steel strap which is placed between the heads of the two hydraulic pistons, and these are placed opposite one another and in a direction transverse to that of the keel. The movement of these pistons is determined by the action of the repeater, which is placed horizontally behind the cylinders of the principal apparatus, and works the distribution box, in this case a double box with four valves, because the repeater has to work simultaneously two cylinders.

The manipulator may be arranged as shown in Fig. 1 (Plate XXXV.), that is to say, in such a way that the angle of the tiller is always equal to the angle which the hand-lever L S makes with the vertical.

DISCUSSION.

Mr. J. MacFarlane Gray (Member of Council): In the specification of my steering engine patent, I have described a hydraulic connection, but it was never made. In that design there are two water tubes leading aft from the bridge to the ends of a sliding cylinder, the piston of which receives motion from the steering gear, and the difference between the travel of the cylinder and that of the piston is the differential motion to actuate the reversing valve. There is a similar water cylinder at the bridge, but it is fixed, and only the piston moves. For these the system now brought under our notice substitutes one small water tube, with a small piston at the bridge and another at the helm. The action is not by measured displacement, as in my plan, but by statical pressure. This is quite new. If the two small rams and their springs can be made to work exactly alike, the system proposed may be usefully employed in many ways in war-ships. It is simpler than the return pipe connection, and it corrects itself for any leakage. I have tried to imagine a contingency in which double friction would be the distinguishing element, but I have failed to find in any condition more than the difference of the frictions acting prejudicially. I think the plan deserves to be thoroughly tested by those interested in the mechanical fittings of war-ships. The testing could be carried out in a workshop where there is any mass moved by hydraulic power. The two small rams and the springs and levers, and a length of pipe could, at little expense, be fitted up experimentally to thoroughly test the capabilities of the system.

The President: Gentlemen, I am sure you wish me to convey to M. Widmann, who I may remind you is one of our recently elected members, our thanks for this paper which he has kindly furnished us.

SOME RECENT HIGH-SPEED TWIN SCREWS.

By E. A. Linnington, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

One of the most interesting and valuable features in the development of naval construction in recent years is the great advance which has been made in the speeds of our war-ships. This advance has been general, and not confined to any particular vessel, or class of vessel. From the first-class armoured fighting ship of about 10,000 tons displacement, down to the comparatively diminutive cruiser of 1,500 tons, the very desirable quality of a high speed has been provided. These are all twin-screw ships; and each of the twins is driven by its own set of engines and line of shafting, so that the propelling machinery of each ship is duplicated throughout. The speeds attained indicate a high efficiency with the twin screws. In all ships, but more especially in high-speed ships, success depends largely upon the provision of propellers suited for the work they have to perform; and where a high propulsive efficiency has been secured, there is no doubt the screws are working with a high efficiency. The principal purpose of this paper is to record the particulars of the propellers, and the results of the trials of several of these high-speed twin-screw ships.

The table gives the leading particulars of several classes of ships, the particulars of the screws, and the results obtained on the measured mile trials from a ship of each class, except C. The vessels whose trials are inserted in the table have not been selected as showing the highest speeds for the several classes. Excepting C, they are the ships which have been run on the measured mile at or near the designed load water-line. On light draught trials speeds have been attained from half a knot to a knot higher than those here recorded. No ship of the class C has yet been officially tried on the measured mile, but as several are in a forward state, perhaps the actual data from one of them may be obtained before this paper is bound in the "Transactions." (See footnote to table.)

All these measured mile trials were made under the usual Admiralty conditions, that is to say, the ships' bottoms and the screws were clean, and the force of the wind

and state of the sea were not such as to make the trials useless for purposes of comparison. On such trials the I.H.P. is obtained from diagrams taken while the ship is on the mile, and the revolutions are recorded by mechanical counters for the time occupied in running the mile. Not less than four runs are made during a trial extending over several hours. The I.H.P. in the table is not necessarily the maximum during the trial, for the average while on the mile is sometimes a little below the average for the whole of the trial. The revolutions are the mean for the two sets of engines, and the I.H.P. is the sum of the powers of the two sets. The pitch of the screw is measured. The bolt holes in the blade flanges allow an adjustment of pitch, but in each case the blades were set as nearly as possible at the pitch at which they were cast.

The particulars given in the table may be taken to be as reliable and accurate as such things can be obtained, and for each ship they are corresponding data; that is, the powers, speeds, displacements, revolutions, pitches, and other items, existed at the same time.

There are a few points of detail about these propellers which deserve a passing notice. In Fig. 1 (Plate XXXVII.), is shown a fore and aft section through the boss. It will be observed that the flanges of the blades are sunk into the boss, and that the bolts are sunk into the flanges. The recess for the bolt heads is covered with a thin plate having the curve of the flange, so that the flanges and the boss form a section of a sphere. This method of construction is a little more expensive than exposed flanges and bolts; which, however, render the boss a huge churn. With the high revolutions at which these screws work a spherical boss is extremely desirable, but of course the details need not be exactly as shown in the illustration. The conical tail is fitted to prevent loss with eddies behind the flat end of the boss, and is particularly valuable with the screws of high-speed ships. The light hood shown on the stern bracket is for the purpose of preventing eddies behind the boss of the stern bracket, and to save the resistance of the flat face of the screw boss. The edges of the blades are cast sharp, instead of being rounded at the back, with a small radius, as in the usual practice; the object of the sharp edge being the diminution of the edge resistance. The driving key extends the whole length of the boss, and the tapered shaft fits throughout its length. These points of detail have been features of all Admiralty screws for some years.

The frictional resistance of screw propellers is always a fruitful source of inefficiency. With a given screw the loss due to friction may be taken to vary approximately as the square of the speed. This is not to say that the frictional resistance is greater in proportion to the thrust at high than at low speeds. The blades of screws for any speed should be as smooth and clean as possible, but for high-speed screws the absolute saving of friction may be considerable with an improvement of the surface. There is no permanent advantage in polishing the blades. No doubt there is some advantage for a little time, and probably better results may thereby be secured on trial,

but the blades soon become rough, and shell fish and weed appear to grow as rapidly on recently polished blades as on an ordinary surface. These screws are of gun-metal: they were fitted to the ships with the blade surfaces in the condition in which they left the foundry.

It appears that within certain limits mere shape of blade does not affect the efficiency of the screw, but with a given number of blades and a given disc, the possible variations in the form or distribution of a given area are such that different results may be realised. The shapes of the blades of these propellers are shown in Figs. 2, 3, 4, (Plate XXXVII.) It will be seen the shapes are not exactly the same for all the screws, but the differences do not call for much remark. Fig. 2 shows the blades for the A screw; C and D have the same form. Fig. 3 shows in full lines the blades of the B screw, and, though very narrow at the tips, they, like A, are after the Griffith pattern. The blades of E and F are of a similar shape, as shown in Fig. 4, and approach an oval form rather than the Griffith pattern.

The particulars of these propellers would be considered incomplete without some reference to their positions with respect to the hulls. When deciding the positions of twin screws, there is room for variation, vertically, longitudinally, and transversely. For these screws the immersions inserted in the table give the vertical positions. The immersion in A is 9 feet, showing what may be done in a deep-draught ship with a small screw. Whatever the value of deep immersion may be in smooth water, there can be no question that it is much enhanced in a seaway. The longitudinal positions are such that the centre of the screw is about one-fifth of the diameter forward of the aft side of the rudder-post. The positions may, perhaps, differ somewhat from this rule without appreciably affecting the performance; but if any alteration be made it would probably be better to put the screws a little farther aft rather than forward. The forward edges of the blades are from 2 ft. to 3 ft. clear of the legs of the bracket which carries the after-bearing.

The transverse positions are decided to some extent by the distance between the fore and aft centre lines of the engines. As regards propulsive efficiency it would appear that the nearer the screws are to the middle line, the less is the resistance due to the shaft tubes and brackets, and the greater is the gain from the wake in the screw efficiency; but, on the other hand, the greater is the augment of the ship's resistance due to the action of the screws. Further, the nearer the screws are to the hull the less are they exposed, but experience is not wanting to show that the vibration may be troublesome when the blades come within a few inches of the hull. Instead of balancing these considerations, it is more satisfactory to state that the average of the clearances between the tips of the blades and the respective hulls is about one-eighth of the diameter of the screw. There are no screw apertures in the deadwood of these ships. All the screws work outwards.

An interesting and noteworthy fact in connection with these propellers is the wide differences in the pitches and revolutions, though the products of the two do not greatly vary. Such differences are extremely rare in the Mercantile Marine for similar speeds, but in war-ships they are inseparable from the conditions of the engine design. As a general rule, with (revolutions × pitch) a constant, an increase of revolutions even with the consequent decrease of pitch allows a diminution of disc and of blade area; other modifying conditions such as the thrust, slip, number, and pattern of blades being the same.

The screws for E and F are interesting, because with practically the same speeds and slips there is a considerable difference in the revolutions. It will be observed that F is a vessel of finer form and a little less displacement than E, and therefore has the less resistance. Although E has the greater resistance and the screw the smaller $\frac{\text{pitch}}{\text{diameter}}$, the higher revolutions permit the use of a smaller screw; but from this example the influence of the high revolutions in diminishing the size of screw does not appear so great as some empirical rules would indicate. The screws for A and B are also worthy of attention. Although the ship A has a much greater resistance than B, the screw of the former is much the smaller both in the blade area and the disc. A's screws, however, in addition to 22 per cent. more revolutions than B, have a much larger slip, and the blades have rather a fuller form at the tips.

Compared with the practice in the Mercantile Marine, the revolutions of these screws are very high, and from the foregoing remarks it may appear that much larger screws would be required for a merchant ship than for a war-ship of the same displacement and speed. There would, however, be several items favourable to the use of small screws. For a given displacement the resistance would be less in the mercantile ship, and with the lower revolutions the proportion of blade area to the disc could be increased without impairing the efficiency. Thus in passing from the war vessel to a merchant ship of the same displacement, there are the lower revolutions favourable to a larger screw, but, on the other hand, the smaller resistance, larger proportion of blade area, and the coarser pitch, are favourable to a diminution of the screw. The ship B has a very large screw at 88 revolutions, but the tips are very narrow. If the blade were as dotted for a diameter of 16 feet, the same work could be done with the same revolutions, but with a little coarser pitch and a little more slip.

There is something to be said for large screws with a small proportion of blade area to disc. For instance, two-bladed screws have frequently given better results than four-bladed screws of smaller diameter; neglecting, of course, the question of vibrations. Twin screws, however, should as a rule be made as small as possible in diameter without loss of efficiency. The advantages of small twin screws are the shorter shaft tubes and stern brackets, deeper immersion, and less exposure as compared with large screws. The exposure of the screws is usually considered an objection, but

perhaps too much has been made of it, for those well qualified to speak on the subject consider that careful handling of the ship would, in most cases, prevent damage to the screws, and that where the exposure is unusually great, effectual protection by portable protectors presents no insuperable difficulty.

The slips of these screws vary from 10 to 17½ per cent., which is certainly not an extensive range, considering the widely different working conditions. Slip as an indication of the efficiency of the screw is not only an interesting subject, but it is often one of importance. In these ships, however, there is nothing about the slips which would give rise to any doubts as to the fitness of the screws for their work. I should like to say a few words upon this slip question, though an adequate treatment of it would require a separate paper of considerable length.

The ancient fallacy that small slip meant a high screw efficiency was supported by the great authority of the late Professor Rankine. Experience proved that considerable slips and efficient screws were companions. The late Mr. Froude offered an explanation of this general rule in a paper read before this Institution in 1878, and gave a curve of efficiency with varying true slip. In Mr. R. E. Froude's paper last year there was a form of this curve, with an arbitrary abscissa scale for the slip, devised to illustrate in one diagram the wide conditions covered by his experiments. In the screws now under consideration the values of the $\frac{\text{pitch}}{\text{diameter}}$ vary only from 1·2 to 1·34, and for these the abscissa values for the same slips do not differ much. Taking the mean value and bringing the slips to a common scale, Fig. 5 (Plate XXXVII.), is obtained, which would approximately represent the relation between the efficiency of any one of these screws and its true slip, if this curve were applicable to full-sized screws propelling actual ships.

The slips in Fig. 5 being real or true, are not the slips of commerce, which are the apparent slips such as those given in the table. Let us endeavour to split up these real slips into the apparent slips and another item, the speed of the wake. We then at once meet with the difficulty that the wake in which the screw works has not a uniform motion. Complex, however, as are the motions of the wake, the screw may be assumed to work in a cylinder of water having such a uniform forward velocity as will produce the same effect as the actual wake on the thrust of the screw. It is then readily seen that the real slip is the sum of the apparent slip and the speed of the hypothetical wake. To make this clear, let V be the speed of the ship, V_s the speed of the screw, *i.e.*, revolutions × pitch, and V_w the speed of the wake; then—

Apparent slip $= V_s - V$.
Real slip - $= V_s -$ speed of ship with respect to the wake.
,, - $= V_s - (V - V_w) = (V_s - V) + V_w$
,, - = Apparent slip + speed of the wake.

If the apparent slip be zero, the real slip is the speed of the wake; and if the apparent

slip be negative, the real slip is less than the speed of the wake. The real slip is greater than the apparent slip, and can never be a negative quantity.

From Mr. Froude's model experiments it appears that this speed of wake for the A class of ship amounts to about 10 per cent. of the speed of the A screw. If this value is correct, then the real slip is (10 + 17·6) per cent., or 27·6 per cent. This is shown in Fig. 6 (Plate XXXVII.), where O is the point of no slip, being 17·64 from the point of real slip. Slips to the right of O are positive apparent slips, slips to the left are negative apparent slips. The vessel F would certainly have a wake with a speed considerably less than that of A's wake. From the model experiments the wake for F is about one-half that for the A class, or roughly 5 per cent. of the speed of the screw. For the ship F, O′ is the point of no apparent slip, and the real slip is (5 + 11·4) or 16·4 per cent. For E, the point of real slip is approximately the same as for F. For B, and D, the positions on the curve would be about the same. The ship B has a higher speed of wake than D, but the screw D has the greater apparent slip. The influence of the number of blades on the scale for the slip has been neglected.

If this efficiency curve were applicable to full-sized screws propelling actual ships, and if the determination of the wakes were beyond question, then we should have a proof that our screws were at or near the maximum efficiency. But as we know from the total propulsive efficiencies that the screws have high and not widely different efficiencies on these ships, we may argue the other way, and say that there is good reason to consider that at least the upper part of the curve agrees with experience obtained from actual ships.

Now take Fig. 6 and consider the general laws there represented. Take the speed of the wake as 10 per cent. of the speed of the screw, which is probably an average of widely different conditions, including many single as well as twin-screw ships. Then this curve shows that considerable negative slips mean inefficient screws; that screws may have very different positive slips without any appreciable difference in their efficiencies; and that very large positive slips and inefficient screws may be companions; for instance, a screw with a large positive slip in smooth water is frequently inefficient at sea against a head wind, which increases the resistance and necessitates an increase of slip. I venture to say that these statements, taken in a general manner, are not at variance with experience obtained from the performances of screw ships.

Before it is possible to satisfactorily decide if this curve applies in a general manner to full-sized screws propelling ships, we require the results of trials of various ships where the screws are working about the region of no slip. Model experiments teach that the scale for the slip varies with the design of the screw, and that with a given screw the speed of the wake (which decides the point of no apparent slip) varies with the type of ship and with the position of the screw with respect to the hull.

Remembering these disturbances, it is not improbable that it may be possible to account for or explain what at first sight may appear departures from the curve.

The diameters of the screws in the table are not compared with the diameters given by the method explained by Mr. Froude in his paper last year; for there are differences in the slips, the proportions of blade area to disc, and to some extent in the shapes of the blades, which are not taken into account in that method. Assuming, however, as Mr. Froude does, a constant proportion of blade area to disc and a uniform pattern of blade, the determination of the diameter for a given set of conditions may, as a rule, be a complete solution of the problem of the design of a screw; but these assumptions do not cover all the necessities of actual practice, which make it extremely desirable to know something about the influence on efficiency of various proportions of blade area to disc, and of the form or distribution of a given area.

At the present time the engineer who designs a screw propeller depends mainly on information such as that given in the table, and as published data of this nature are somewhat rare, I hope the paper will be interesting to the Institution generally, and useful to those members who may have to design the screws of high-speed ships.

Note.—For Table see next page.

PARTICULARS OF SOME RECENT HIGH-SPEED TWIN SCREWS.

SHIP	A	B	C*	D	E	F
Length, feet	325	315	300	300	220	250
Breadth, feet	68	61	56	46	34	32½
Draught on Trial — Forward ...	26ft. 2in.	24ft. 6in.	21ft. mean.	15ft. 6in.	12ft. 10in.	13ft. 1in.
Draught on Trial — Aft	27ft. 3in.	25ft. 6in.		19ft. 9in.	15ft. 2in.	14ft. 7in.
Displacement, tons ...	9,690	7,645	5,000	3,584	1,560	1,544
I.M.S., square feet ...	1,560	1,287	1,000	744	438	392
Speed of Ship, knots ...	16·92	17·21	18·75	18·18	16·91	17
I H.P.	11,610	10,180	8,500	6,160	3,115	3,045
Revolutions, per minute..	107·2	88	120	122·6	150·4	132·1
Pitch of Screw	19ft. 5in.	22ft.	18ft. 6in.	17ft. 6in.	12ft. 7½in.	14ft. 9in.
Slip, per cent	17·6	10	...	14·2	9·7	11·4
Diameter of Screw ...	15ft. 6in.	18ft.	14ft. 6in.	13ft.	10ft. 6in.	11ft.
Diameter of Boss ...	4ft. 4in.	4ft. 11in.	3ft. 9in.	3ft. 5in.	2ft. 9in.	2ft. 10in.
Number of Blades ...	4	4	3	3	3	3
Blade Area of one Screw	72	87	60	47	24	24
Shape of Blade	Fig. 2	Fig. 3	Fig. 2	Fig. 2	Fig. 4	Fig. 4
$\frac{\text{Pitch}}{\text{Diameter}}$	1·25	1·22	1·3	1·34	1·2	1·34
$\frac{\text{Disc}}{\text{Blade Area}}$	2·62	2·92	2·75	2·82	3·6	3·96
Immersion of Screw ...	9ft.	5ft. 3in.	...	4ft. 4in.	2ft. 9in.	1ft. 10in.

* The following results were obtained on a trial made in April, 1887, at the designed draught of water :— I.H.P., 8,620 ; speed, 19 knots ; revolutions per minute, 119.

DISCUSSION.

Captain J. D. Curtis, R.N. (Visitor): My Lord, I have only a few words to say upon this paper, and my remarks will be more in the shape of a question. The late Professor Froude and the late Mr. Robert Griffiths said if the screw was about two-thirds of its diameter away from the stern-post, speaking of a single screw, it would be more efficient, inasmuch as it would not act on what sailors term the dead water, which practically speaking is the inflowing water. At the late "Inventions" I saw a model of one of the Trinity yachts which had an aperture in the stern, in which the screw apparently drew out the circulating water round the condenser, and I should like to ask whether that was due to the action of the screw, or the action of the following water round the ship. In my opinion the screw draws the water through the ship referred to; as the late Mr. Griffiths experimented with a tank inside, near the stern, and he could always empty it when the screw was in action; when the screw was not going it filled, apparently demonstrating that the screw is generally placed too near the ship's run, acting detrimentally upon the inflowing water.

Mr. E. Blackmore (Associate): My Lord, as I was lately a member of the firm which I believe first introduced screws overlapping each other through a space in the stern-post, may I be allowed to make a few remarks? I believe that all the cases in which screws of less diameter have been found more efficient in Her Majesty's war-ships, have been cases in which the propellers have worked against the deadwood of the vessel. I am not able to speak professionally on the point, but I think as far as our experience goes of working screws overlapping each other through a space in the stern of the vessel, and from the efficiency we have attained through pursuing that course, it may be shown by experts that the screws of Her Majesty's ships which have been reduced in size have proved themselves more efficient simply because they have been drawn away from the deadwood of the vessel and allowed to work in more solid water. Our friend who has spoken just now (Captain Curtis) has given me the opportunity of making this remark. I remember very well indeed when first I showed the model of the overlapping screws to some friends in London, Mr. Griffiths himself happened to be present, and after looking at it for some time he turned round to my friend who had introduced me to him and said, "My dear sir, these gentlemen have attained my patent in another way; they have simply attained by their application of the overlapping propeller through the aperture in the stern of the vessel, what I have been seeking to do all along by withdrawing my screws from the stern of the ship itself." He said, "They have simply got rid of the wake water of the vessel, and their screws are working in solid water." I cannot give you at the moment any data for efficiency, but I believe all our friends who have had anything to do with these ships will admit that they have been very efficient indeed. I think it is one of those things which should be taken up, and that a good deal more may be attained than has been done in the past. I am satisfied that propellers working in screw spaces, and allowed to overlap, are much more efficient (although it does not look like it on the first blush) than those which are allowed to work alongside the deadwood of the vessel. There is another point which I would like to call attention to, and it is this: we have heard a great deal about the deficient steering of twin-screw ships. In the vessels we have built we find that the overlapping of the propellers not only does not detract from the efficiency of the steering, but actually adds to it; and I think anybody who is acquainted with the working of screws, as I was in my younger days, will at once see the reason. That is, that when propellers overlap as much as we have already made them, to the extent of 18 inches to 2 feet over each other,

when either of those propellers is turned ahead the action of the water from the propeller is thrown immediately against both sides of the rudder, whereas the water from propellers working alongside the deadwood of the vessel, passes away on one side of the rudder only, and its action is lost for steering purposes. I should like if engineers generally would turn their attention more to the features of this case, and work it out in the direction I have indicated.

Mr. W. John (Member of Council): My Lord, I wish to bear testimony to my appreciation of the high value of this paper. The subject of twin screws and the proportion of pitch to diameter of twin screws, is one, I think, we are in the infancy of at this time. I do not think either in the Mercantile Marine or in the Royal Navy we have anything like the data to work on that we have for a single screw, and that is only natural, because of the comparative fewness of the ships yet built with twin screws. Mr. Linnington has given us here a very valuable paper, which will be of interest to all of us. He mentions in this table that the proportion of the pitch to the diameter varies from 1·2 to 1·34. I have in my mind a couple of little twin-screw steamers where the proportion of the pitch to the diameter comes nearly to 1·5, which is outside the range of those limits, and I remember a few years ago on one of these vessels the propeller being changed and the pitch being increased, and the result was a considerable improvement; and I have often puzzled my head, knowing that the proportions of pitch to diameter were so outside of what we do with single-screw ships, and wondered what the cause of it was; and I do not know now, but I believe that you can go with quick-running, twin-screw engines to a larger proportion of pitch to diameter than you can with a single screw. There was the change in the *Iris*, when she was first engined with the pitch equal to the diameter. We know the two knots, or thereabouts, that was gained when the diameter was reduced 2 ft. and the pitch increased 2 ft. In the ships I am speaking of I do not remember the figures, and cannot give them; I am speaking from memory now, but in these small twin-screw propellers with a very large pitch compared with the diameter, the results were exceedingly good, and I wish the Admiralty would try further experiments with their twin-screw ships in the direction of a greater proportion of actual pitch compared with the diameter. I do not know whether the reason of it may be something of this kind. We will take an auxiliary ship—one with steam and sail, with a single screw. If you are running before the wind, helped by your sails, it stands to reason that you can do with a coarser-pitched propeller better than under ordinary circumstances. Whether the fact that where you have two screws, one helping the other, the ship going faster than either screw could drive her, affects the question similarly or not, I do not know. I think it does to a certain extent, as much as the position of the screws themselves; and it is a direction that I have been wishing for an opportunity of making experiments in, and the Admiralty, with all their twin-screw ships—many of them sister-ships—for a comparatively moderate expense, could do an enormous amount of good to the Mercantile Marine, as well as to the Admiralty service, if they were to push investigation in that direction.

Admiral A. F. R. De Horsey (Associate): My Lord, it may be interesting to Mr. John to hear that the experiments he speaks of with the single screw I have tried very often. In a ship which I commanded some twenty years ago, the *Aurora*, we had a feathering screw, and when sailing and steaming we commonly altered the pitch of the screw, according to the strength of the wind, and with great advantage. It was a screw you could alter whilst it was in motion, which we found to be a very great convenience. As the wind freshened we coarsened the pitch, and when we wanted to stop the engines we coarsened the pitch more and more, so as to bring the screw-blades right fore and aft, and then stopped the engines, so that we never stopped the way of the ship in changing from steam to sail alone. I do not know whether I make myself clear.

The President: Yes; quite.

Admiral De Horsey: I was very much interested in Mr. Linnington's paper, and I would ask him, when he replies, if he would favour me with a piece of information which I think would be of interest to the meeting. This very interesting table is, as I understand, taken on the measured mile; and, as we know, the measured mile trials are in smooth water, and very properly so. Now, the question of twin screws *versus* single screws is one, I think, of the greatest importance at this moment. The reason we have taken to twin screws in the Navy will be patent to everyone. The twin screw may be better, but it is not on that account we have adopted it; it is for the notable reason that it gives two strings to our bow. If one is broken we have the other to rely on; and not only that, but it gives us another great advantage, that of enabling us to have a fore and aft bulkhead, which with a single screw is difficult of attainment, if not impracticable. But the point which I wished to ask Mr. Linnington if he could give us any information upon was this: these results being obtained under favourable circumstances, I should like to know whether the advantages of twin screws are equal when you come to strong headwinds and heavy seas? So far as I am aware, the Mercantile Marine have not as yet looked favourably on twin screws. Our fastest and finest passenger ships are, I believe, single screws, and I apprehend it is for this reason, that when they get into very bad weather—I may be wrong—the single screw has the pull. No doubt Mr. Linnington will be able to clear up this point, and I think that information may be interesting to the meeting.

Mr. A. Spyer (Member): My Lord, I should like first to express my appreciation of the very interesting figures which Mr. Linnington has given us this evening, which are of special value now, having regard to the possibility of the extension of the twin screw system to the Mercantile Marine. Referring to Mr. Linnington's paper, on the first page he states: "In all ships, but more especially in high speed ships, success depends largely on the provision of propellers suitable to the work they have to perform." I entirely agree with that statement, but I think it might be amplified with advantage, inasmuch as twin screw propellers, I think, should be designed—in fact, propellers of all descriptions—not only for the work they have to perform, but relatively to the hull on which the work is to be performed. Now, if possible, it appears to me that we ought to design the machinery by commencing at the propellers, putting in propellers designed to suit the hull, and then designing the engines, if we knew exactly how, so as to turn those propellers and so obtain a result of maximum efficiency. There are two cases given here in the table, I think they are marked A and B. In examination of those it appears that two propellers of very different dimensions, but doing very nearly the same amount of work, have both given a very good and efficient result; and I think it will be found on close examination that the larger propeller in this case—the propeller is 18 ft. in diameter—has given rather the best result; but it should be observed in case A that the very high speed obtained by the ship might probably have not been obtained at all had it not been for the small propeller fitted. That exemplifies a very considerable difference which exists in the modes of design which must necessarily be adopted for ships of war and merchant vessels. We are obliged in designing propellers for ships of war to attempt to obtain the highest possible speed under the circumstances, and that result is not necessarily coincident with a propeller of maximum hull efficiency. It may be possible that that speed may be obtained with a propeller of rather lower efficiency. On the other hand, for mercantile purposes, coal consumption is obviously of paramount importance, and the speed of any particular vessel must be obtained with the smallest possible amount of I.H.P., that means to say a propeller of maximum total efficiency. There is another question in this paper, on page 399, on which, if your Lordship will allow me, I should like to make an observation. He states that the positions of propellers may perhaps have to differ somewhat from the rule he had just previously

given without appreciably affecting the performance, but if any alteration be made it would probably be better to put the screws further aft rather than forward. I am aware that what I am going to say may possibly be considered rather unorthodox, but I am inclined to think that the longitudinal position of the propellers is of very great importance in twin-screw vessels. Many gentlemen here will recollect that in H.M.S. *Invincible* it was originally found the alteration of position of the propellers, shifting them rather further aft, produced a very considerable improvement. I think half a knot was gained in speed by shifting the position of the propellers. Again, we have the very well known case which Sir Nathaniel Barnaby called attention to here, of the *Nelson* and the *Northampton*, in which there was a difference of speed amounting to one knot in full power in those sister ships. It is perhaps possible that a portion of the difference of speed may have been due to the longitudinal position of those propellers. More recently, in a small pinnace, in a case with which I am acquainted, the experiment was actually tried; the propellers were shifted about six or seven inches further aft, and the boat was again tried on the mile. With about 10 per cent. less I.H.P. she obtained 3-10ths of a knot more speed, and that additional speed, I may say, was gained in very, very different weather to that in which the original trial was made. It was in fact what is called "6 rough," and those who are acquainted with the Admiralty measure of weather will understand that "6 rough" for a boat 48 ft. long is very uncomfortable weather indeed. The original trial was made in what is called "1 smooth." On the whole I think the longitudinal position of the propeller is worthy of somewhat more extended notice than Mr. Linnington has given it to-night. I am, however, sure that he has earned our thanks for the very able paper he has read us this evening.

Mr. S. W. Barnaby (Member): My Lord and Gentlemen, I would like to put what Mr. John said about the design of twin screws as compared with single screws, in the shape of a distinct question to Mr. Linnington, which probably he would be good enough to answer—that is, whether in designing twin screws for a vessel, say of 8,000 I.H.P., he would make each screw, which would have to take 4,000 I.H.P., of the same diameter as a screw for a single-screw ship of 4,000 I.H.P., and the same speed? Have you that clearly, Mr. Linnington?

Mr. Linnington: Yes, I think so.

Mr. Barnaby: Thank you. In high speed vessels, unfortunately—unfortunately, at least, from one point of view—the faster they go for a given power the smaller the diameter of the screw has to be, and the larger the pitch, so that in very high speed twin-screw vessels we find the ratio of pitch to diameter coming out very great indeed. The largest in the table is 1·34. Mr. John said he was acquainted with 1·5.

Mr. John: About 1·5.

Mr. Barnaby: I find that in a twin-screw torpedo boat, which we are proposing to try next week, and in which we hope to get a high speed, we have a ratio as high as 1·82. Whether she will be successful or not I cannot say, but they were obliged to be very small screws, and in order to get the proper number of revolutions—not too high—the pitch has to be as large as that. Then there is another question which I should like to ask Mr. Linnington. In the case of the *Inflexible* it was found, I believe—owing to the position of the screw, it may be—that the hull plates immediately over the screws were damaged. I would like to ask him what he thinks was the cause of that. It has been a common notion that the rotation of the water in the screw race produces dispersion—that is, that the column of water projected by the screw takes somewhat the form of a truncated cone, having the screw for the apex. I think that where the propeller is properly immersed and does not get air, that

that is not the case; that the column is really fairly cylindrical, although in considerable rotation; and there was a paper read here last year by Mons. Marchal, of the French Navy, in which he took the same view, and stated that from observations of the action of the propeller in the phosphorescent waters of tropical seas, where the column could be seen, it really took the form of a twisted rope, which gradually uncoiled itself as it passed astern, so that I am inclined to think that the accident to the hull plates of the *Inflexible* was not due to the centrifugal action caused by the screw when going ahead, and I would suggest it was in going astern that it happened, because when screws are going astern they invariably draw air at the start, and as soon as they do that centrifugal action takes place to a large extent, and I think that is when the bottom of a ship is likely to suffer. As far as the position of twin screws goes, I am not able to say anything, but I mentioned last night that we had found an advantage in bringing the screw further forward, but I should have said that that is associated with a particular form of stern; the stern is carried over the screw, rather than the screw being carried nearer the hull. That may have led to some misconception, but we certainly have found an advantage by collecting the water which has been rubbed by the ship in a sort of tunnel over the screw. It is that which I wished to draw attention to last night. I think, my Lord, that is all I have to say.

Mr. Crohn (Visitor): My Lord, I should like to ask Mr. Linnington whether the propellers he mentions in this table revolve outwards or inwards. I think it is of very great importance in twin screws to know in which direction they revolve. I may mention that the firm with which I am connected have got, within the last few days, some uncommonly good results with twin screws. Their propellers revolve outwards, but I have also known cases in which the propellers revolve inwards and superior results are said to have been obtained, and I should like now to know whether this discussion would bring out any opinions as to which is the best, or any facts as to which is the best. I should also like to say that a coarse pitch, so far as I have seen, is decidedly the best —very coarse pitches are sometimes found to give the best results.

Mr. Becket Hill (Associate): My Lord and Gentlemen, a mere commercial man is naturally reluctant or diffident of offering any remarks in the presence of so many professional gentlemen, but as the managing owner of probably the largest mercantile steamers possessing twin screws, and as I know that professional gentlemen are as anxious to hear facts as theories, you may perhaps be willing to listen for a moment to some of the experience that I have gathered during the past three or four years from the working of the steamers *Ludgate Hill*, *Richmond Hill*, and *Tower Hill*. These are all steamers of over 4,000 tons register, and they indicate when we work them at full speed, which in these times we cannot always afford to do, about 2,500 I.H.P. Before I and my friends built these steamers, I had built some very large tug boats on the twin-screw principle. They are pretty well known in the shipping world, the *Stormcock* and the *Gamecock*, and from the experience which we have had with these vessels, and also from a paper which I read of Mr. White's, I thought it desirable to try the plan on a larger scale, and it appears that I was simply a little before my time, because at the present moment I believe that some of the fastest steamships intended for the Atlantic service now being designed, and the building of which has commenced—(I believe there are four of them now building, of enormous size and speed)—are all to be twin screws. I think, my Lord, we see in this an illustration of what we in the commercial world owe to the Navy. It is from the Navy after all we get our ablest men, and our most complete information. We never have in the Mercantile Marine the time, the staff, or the opportunity to make these extensive calculations, and to obtain these data which are so liberally furnished to us by our Naval officials, and to which a great part of our own achievements in the commercial marine is due. We are, as I say, infinitely indebted to gentlemen like the

writer of this paper. I would point out one matter which I am sure will be very much appreciated by the firms who are building the large and powerful steamers I have alluded to as a most interesting and important fact, and that is what the author of the paper has demonstrated to us, namely, that we can manage to get large I.H.P. applied successfully through a screw of very moderate diameter. That is a very important matter. The great obstacle to the extension of twin screws in the Mercantile Navy has been the fear that the projection of these screws would make the vessels difficult to handle coming in and out of dock; but the author shows us that, with a properly designed engine, a very large power can be put to a very moderate-sized screw, and I am sure the data given here will be most carefully investigated by those gentlemen who are building these vessels, if they wish to produce a successful result. The paper has thus been most opportune. There is another point alluded to by Mr. Blackmore. He says that he had tried the cutting away of an opening in the stern of the vessel and allowing the screws to overlap. It is apparent that if that is done one advantage of the twin screw is certainly lost. The weakest part of the ordinary single screw is the stern or rudder frame. So many accidents occur through the rudder-post being carried away owing to the weakness of this opening in the stern of the vessel. That is a danger the twin screws avoid entirely, your ship being carried out right solid to the rudder-post. If Mr. Blackmore's experience was correct, and if there were great advantages in making this opening, it is probable we should have to do it, but I am inclined to think from all I have seen and heard, and from some little experience of my own, that there is not the least necessity for making any opening whatever. There have been some twin-screw boats built at Liverpool since mine were built that have that opening, and I never heard that they were especially efficient. One instance I can give is the case of the *Gamecock*. The *Stormcock* was built by Laird's and the *Gamecock* was built by Messrs. Brassey. They were identical boats, and I thought that possibly I might get a little increase of speed in the latter boat by cutting away the blades of the propellers, and I had six inches cut off the tips to give more clearance, but instead of an improvement I found it was a distinct disadvantage, and I subsequently had to put a piece on again. Since then, every vessel I have had built of the same class, I have always put the point of the propeller as near the deadwood as I could, without actually touching it, and in both the large steamers and the towing steamers the distance is very small, a very few inches. We have been asked to-night whether the screws work outwards or inwards best. I never had any screws that worked any other way than outwards; I have heard of screws that worked the reverse, but as they have not been used in practice, I suppose it was not found a desirable method. Then another point which has not been alluded to is this: I did not find, when the vessels came in to be docked, so much pitting at the ends of the propellers as you notice in large screws; whether it is that our screws are smaller in size, or owing to the double screws, or whether it is due to the aperture in which the single screw works, it is a fact that there is much less pitting in our propeller blades. That is another advantage for twin screws. As to safety, they are pre-eminently desirable, and the Navy has set us an excellent example. With the twin screw you have always two strings to your bow. Now that so many passengers are carried on one bottom—so many hundreds of valuable lives—there is a great safeguard in having a double set of engines and screws. On two occasions my vessels have left New York, and within a day or two accidents to machinery, which would have entailed towing back again and repairs in a foreign port, have been rendered quite immaterial by her possessing two screws. The *Richmond Hill* broke her cylinder two days after leaving New York, and she came on with her second set of engines, and was only one day longer than usual over her passage. I have only now to thank the author of the paper for the data which he has given us. I am sure it will be most valuable to all future designers of twin-screw ships.

Mr. E. Blackmore (Associate): I would just like, my Lord, to give one word of explanation with regard to what Mr. Hill has said as to the strength of the stern-posts. I do not think we need be under the slightest fear with regard to it, because there is no strain on the stern-post whatever, any more than that naturally brought to bear upon it by the rudder. There is another point we consider of exceeding great advantage, and that is this, that we get the opportunity of fastening the bars or arms which carry up the after brackets to a solid piece of forging instead of being obliged to strengthen a portion of the framing and plating of the ship to carry up those brackets. We have invariably bolted the brackets through and through the heavy forging itself, and never, in one instance out of about sixty twin-screw steamers, have we had a single slip or disadvantage from having the double stern-post carried out in that way.

Mr. W. H. White (Vice-President): My Lord, I would ask Mr. Hill, with your permission, if he would tell the meeting whether, in the docking and undocking of the twin-screw vessels of his line, his experience confirms the very prevalent idea in the Mercantile Marine that twin screws are liable to serious and frequent damage?

Mr. Becket Hill: I was afraid, my Lord, that I was trenching on your time, or I would have made some further remarks on the point that has just been raised. We have found no difficulty in docking and undocking our vessels. We have docked and undocked them in Liverpool frequently. We have docked and undocked them in London continually, for years. In fact, while with our single screws of smaller size we have to employ one or two tugboats to assist them, we never have to do so with the twin screws. They are 420 ft. long and 45 ft. to 47 ft. beam, and therefore vessels of very large size to handle in a river like the Thames. I may notice here that my boats will probably be under more disadvantageous conditions in this respect than the high-powered steamers that are to be built, as I see, by the paper just read, propellers of a diameter of 15 ft. 6 in. have been made to indicate 11,610 I.H.P., so that the great twin-screw Atlantic steamer now building, which is to have a beam of something like 65 ft., may have her screws very much more protected than my vessel with a beam of 47 ft., and a propeller of the same diameter.

Mr. W. H. White: My Lord, I knew it would be of the greatest interest to the meeting, and to shipowners generally who are contemplating the use of twin screws, if Mr. Hill would give us that piece of information from his experience which he has given. When I read the paper to which Mr. Hill has alluded, in 1878, on twin screws in deep draught ships, I made a remark which I think has some bearing on the paper of to-night. I said that in considering the relative efficiency of single and twin screws in ships of deep draught, it must be borne in mind that up to that date there was only limited experience in the choice of the best types of twin screws, or the positions of these screws, and many of the details about them. With single-screw ships, on the contrary, we had at that time something like twenty-five or thirty years' experience to go upon. What has happened in the last ten years has added so much to our experience that it may be now asserted safely that twin screws are at least as efficient in ships of deep draught as are single screws, and on ships of light draught they are more efficient. It is not to be wondered at, therefore, that as higher speeds and greater powers have become necessary for certain services, shipowners generally who are contemplating the building of vessels to fulfil those services, should follow the example which was so gallantly set in the construction of the vessels of the Hill line. There can be no doubt, I think, that in adopting twin screws for these vessels, the question whether or not they shall overlap is one for very serious consideration, and it is interesting to know Mr. Hill's opinion, based upon experience, that there is no objection to the absence of that overlapping or to the projection of the screws to the

extent that is found necessary in the ships of his line. Of course it is a matter in deciding which each case must be dealt with independently. It may well happen that with a moderate power in vessels of considerable size, such as those of the Hill line, the screws are well sheltered; whereas in the large, swift ships which are now contemplated, which must necessarily carry larger screws, this difficulty will be more apparent. But this is simply a detail, and I am sure that we shall all be glad to know that in the future these magnificent English ships, which will be practically incapable of doing anything under sail, will have in them duplicate machinery, duplicate propellers, more minute subdivision, and everything that makes for the greater safety of life at sea. The real value of this paper seems to be in its record, in a convenient form, of the particulars of the ships, the screws, and the performances of the screws in a good many vessels of high speed; and, if it is not asking too much, if Mr. Sydney Barnaby and Mr. Crohn could add to this table some particulars of the actual performances of the screws, in the smaller twin-screw vessels of remarkably high speed which are now being tried, it would add greatly to the value of the information here given.

Mr. E. A. Linnington (Member): My Lord, in replying to this discussion, I feel that it has been of such an interesting and complete nature that my remarks are likely to appear somewhat unsatisfactory in comparison with it; but I will endeavour to take the questions and the observations which have been made in order. First, with respect to the question of Captain Curtis, which referred to the longitudinal position of the single screw. Well, as a matter of fact, in single-screw ships the most convenient position of the screw is just forward of the rudder. The screw being there, the run of the vessel should be such as to allow a good supply of water to the screw. With a suitable run of water to the screw, small variations of longitudinal position have no appreciable effect on the propulsive efficiency. Where a screw has been placed farther aft, and a better result secured, it has probably been due to a better supply of water, for the augment of the ship's resistance and the screw's gain from the wake probably balance one another. Mr. Blackmore referred to Admiralty screws that were reduced in size, and which were put more clear of the deadwood, and apparently gave better results. I do not know what screws Mr. Blackmore may have been referring to. The only swift ship I can now call to mind in which the Admiralty have reduced the size of the screws is the *Iris*. It is a fact that the screws ultimately fitted to that ship were smaller than those put upon her in the first place; but it is also a fact that the best result was obtained from screws of practically the same diameter as the original screws. The difficulty in the *Iris*, so far as speed was concerned, was not that the screws were too large in diameter, but that there was too much blade area within the disc. The small screws were fitted as they caused the less vibration. Mr. Blackmore also spoke of the inefficiency of steering in certain twin-screw ships. If there is any difficulty, I believe the remedy is very simple. It is very much a question of the size of the rudder. There need be no bad steering of twin-screw ships in the Mercantile Marine. Mr. John's remarks as to the proportion of pitch to diameter were very interesting. As to experiments with screws of different pitch ratios, so far as my experience goes I have not observed anything in actual practice which would indicate that any increase of pitch to diameter which we are likely to meet with would lead to any difference in efficiency; and Mr. Froude's model experiments show that up to a pitch ratio of 2·2 there is practically no difference in efficiency. If there is a difference, the larger pitch ratios appear slightly more efficient. Of course, whether these results of model experiments would apply to full-sized screws upon actual ships I cannot say. The revolutions are practically determined by the pitch, and if we alter the pitch much we have to alter the revolutions, and then comes in the question of the engine design, so that the trial of screws of different pitch ratios in the same ship, or in sister ships, is not such a simple matter as it appears at first sight. Admiral De Horsey spoke of these speeds as

the measured mile results, and appeared to think it was possible that the twin screws would not appear so satisfactory at sea in comparison with the single screw as they do in smooth water. Now, it is one of the merits of the twin screws that at sea they have the advantage. Conditions of weather and trim which bring the single screw out of water and make it extremely inefficient, have no appreciable effect on the twin screws. In vessels of deep draught especially the twins are well immersed, and pitching and rolling motions do not cause emersion of the screws; and they are, as compared with the single screw, more efficient at sea than in smooth water. That is one of the great advantages of twin screws, and you may expect your ships to make a more uniform passage with twin screws than with a single screw. Mr. Spyer, for whose remarks we are all much obliged, spoke of designing the screw for the hull, and taking the screw as the basis for the engine design. There is no doubt that may be right in principle; but, if you have to design your screw for the hull, it really means that you must know all about the water the screw works in, and at present we know but little of the ship's wake. As to the longitudinal position of twin screws, there is no doubt that in a ship of full form, or in a ship where the screw comes well forward and is on a full section of the vessel, the longitudinal position is of importance, and better results may be obtained by placing the screws further aft; but in the ships referred to in this paper the runs are very fine, and the screws are well clear of the hull, and they come on a fine section. In these ships any small difference in longitudinal position probably would not affect the performance. The reason why I have said in this paper that, if any alteration were made, it would probably be better to put the screws farther aft rather than forward, was that in some twin-screw ships built for foreign Governments, which gave very satisfactory results, the screws were a little farther aft than the positions here given. With regard to Mr. Barnaby's request for the diameter of the propellers for single-screw and twin-screw ships, that goes into a very wide question. It really brings up the whole matter of empirical rules for screw propellers, and that I have carefully avoided in this paper, because it is one to which a separate paper might well be given. I am sure if Mr. Barnaby will favour us with his practice for single and twin screws we shall all be very much obliged. His question could not be answered offhand with any satisfaction to Mr. Barnaby or to myself. I may say that in the Admiralty we do not go much by empirical rules in determining the proportions of screws. There is a method of procedure which has to be applied with a little judgment begotten of experience. The method of procedure and the experience are not readily expressed so as to give satisfaction to a scientific audience. With respect to the plates near the screws of the *Inflexible* being damaged, I may say that the circumstances are not well known to me, but Mr. Barnaby's suggestion appears reasonable. I will not offer any definite opinion myself, for, unless the facts are exactly known, any opinion on the matter is not worth much. There are no such occurrences in these days. Mr. Crohn asked the question, How do the screws revolve? They revolve outwards; that is, in the upper part of the disc the blades move away from the hull. This fact may not be known to everyone present, although it is the general practice with twin screws. The advantage of driving outwards is a little more speed, and perhaps less vibration, than where the screws work inwards. I am very much obliged for the friendly notice which Mr. Hill has taken of this paper. I am sure that with his great experience with twin screws in merchant ships, the remarks with which he has favoured us must be especially valuable to gentlemen connected with the Mercantile Marine. With respect to the greater pitting of the single screw as compared with the twin screws, to which Mr. Becket Hill referred, I think that must be due to the fact that the tips of the blades of many single screws draw in a considerable quantity of air, and it is probably owing to the presence of air that the pitting takes place. Mr. Hill's reply to Mr. White's question about the possible damage to twin screws in docking is especially

valuable. A good deal has been said as to the probability of injury to the screws under such circumstances. Mr. Hill's experience should completely dispose of the objection that has been freely mentioned, viz., the possible damage to the screws when docking. I think Mr. John told us at Liverpool of a case where a captain did damage a screw, but it was such a lesson to him that he never injured another. I think, my Lord, that is all I have to say in reply to the discussion; and it only remains for me to thank the meeting for the attention given to this paper.

The President: Gentlemen, I am sure you will desire me to convey to Mr. Linnington your thanks for his valuable paper. He has evidently given great attention to this subject, which is comparatively novel, but of immense importance, and I am sure you will all be very grateful to him for giving you the result of his valuable experience and labours upon that subject. I may convey to him, I am sure, with your entire approval, your thanks for his valuable paper. Now, gentlemen, the next paper that stands upon our programme is by a gentleman who is in America, Professor Thurston. I am going to make a proposal to you. Of course, I am not a judge of these matters, but it has been suggested to me that it is not a paper that could with any advantage or convenience be read and discussed, and therefore I am going to propose to you that it should be taken as read. Of course, we are extremely obliged to the author for sending us this paper, and if we adopt this course it will not I hope be looked upon in the least degree as a slight; but really the subject with which the paper deals is a very complicated one. The paper itself is of great length, and time, as we all know, is of some value. I am sure it is a paper which may be taken home and read, marked, learned, and inwardly digested with immense advantage. I propose to you, therefore, that it be taken as read; but if anybody has any objection to that course I hope he will express it. I now make the proposal to you, gentlemen. Do you agree? Those who are in favour of the suggestion I have offered will hold up their hands; the contrary, theirs. Then, it is taken as read, gentlemen, with your unanimous consent. Then, we go on to the next; and the Secretary will be instructed to convey our thanks to Professor Thurston for his valuable communication.

FORMS OF FISH AND OF SHIPS.

By Professor R. H. Thurston, Associate.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

The problem presented to the naval architect, in its most general form, may be, perhaps most concisely and precisely stated as follows:—To seek the best method of transporting a stated weight of merchandise or number of passengers from one port to another, making the time occupied a minimum, and the cost the least possible consistent with safety and comfort. The principles governing the design of the form of any proposed vessel have been fairly well settled, and the power which must be supplied to drive any well-formed ship at any prescribed speed can be very exactly calculated; but it is not yet fully ascertained precisely what form, and especially what proportions of length to other dimensions, will give minimum resistance for a vessel of any given tonnage, although it is probable that these data are very closely approximated to by experienced and expert designers and builders.

It is considered well established that the resistance of every ship consists of two principal parts, the wave-making resistance and the frictional resistance of the hull against the fluid in which it moves. In well-formed vessels the frictional element is enormously the greater of the two, and it, only, requires to be considered. It is not, however, the friction of the wood or iron of the hull upon the water that measures this resistance. The observer who places himself in a position to study the action of a moving vessel upon the water alongside, will at once perceive, as the craft is set in motion, that the layer in contact with the side is carried on with the ship, and that the adjacent layer exterior to that moves at a less velocity than the vessel itself; and, as layer after layer is considered, each more distant than the preceding, the motion of water and ship becomes relatively greater, until, at some little distance from the ship, the water is at rest, and the relative motion of the vessel a maximum. The ship thus moves in a shell, which it carries along with itself, and the friction is that of water on water, and not of the hull on the fluid. This is equivalent to the resistance of a hull perhaps 20 per cent. larger than the ship itself, and it is at once seen that the dimensions of the moving mass exceed those of the ship by the thickness of this cushion of fluid carried along with it. The distance to which this effect is appreciable is much greater than is

usually realised, and is so well understood by seafaring men that an old pilot always objects to the proximity of a slower vessel running alongside, on the ground that his own ship must, in such a case, expend power in dragging the other along.

Another effect of this adhesion of the nearer layers of water to the ship is to set up currents running in the direction of motion of the ship, and thus causing a less relative motion of the water toward the stern of the ship than near the bow. This, in turn, causes a reduction of the intensity of the frictional resistance, as we pass from bow to stern, per unit of area of surface of hull, and the difference is often so great as to produce a very important and beneficial effect, by reducing correspondingly the power demanded for propulsion. It can easily be seen that this reduction of friction by decreased relative motion of ship and fluid may go on until the maximum speed of the middle surface of the cushion above described becomes one-half that of the ship, at which point the friction per square foot is reduced to one-fourth that at the stem of the vessel. Thus the engine power expended at the bow is utilised in reducing resistance further aft, and the efficiency of propulsion is correspondingly improved. It is in this and other ways that the lengthening of steam vessels, so far beyond the proportions formerly supposed to be the limiting ratio of length to breadth or depth, has been found to give increased economy of transportation at sea. It would seem, from present experience and practice, that the best proportion is not far from ten to one, instead of seven to one, as has been stated by earlier writers. This modification of resistance with length of surface exposed to fluid friction, has only been recently discovered and investigated experimentally. It was observed by the late Mr. Froude, and illustrated in his now well-known researches. The law of variation has not yet been fully determined.

It has been long known that the resistance of surfaces in fluids varies approximately as the square of the velocity of motion, and that this rate varies somewhat under various circumstances. Mr. Froude found that the rougher the surface the higher the index, its value approaching 2 as the surface becomes rougher, and falling to about 1·85 for the smoothest bodies with which he experimented. Similar results have been obtained by other investigators. Where the form of the body is "unfair," as the naval architect would say, the resistance may increase in much higher ratios, and vessels moving at speeds far above those for which their forms are adapted must often expend power at rates which increase with most extraordinary rapidity; but they often pass a maximum, and the ratio may fall again to something like the normal. Mr. Froude found the resistance, expressed in pounds on the square foot, between solids and the water in which they moved, to be as follows:—

Smooth metal	0·232
Varnished surface	0·226
Fine sanded surface	0·337
Medium sanded surface...	0·456

And these figures have since been very closely confirmed by another method of experiment by Professor W. C. Unwin. The last named investigator also found that the resistance decreased very rapidly with increase of temperature. A change of 5° Fahr. caused a decrease of one per cent. It is evident that this means a very perceptible difference between the North Atlantic and the tropical seas; and a "Southern passage" gives other gains than those of good weather and smooth sea.

It is evident that the resistance to the motion of a smooth body, like the hull of a ship, must vary somewhat with its form, apart from the variation due to differences in wave-making action. Thus a straight-line surface and a curved surface, moving in the same line or path, will not meet the same resistance from simple friction, even where they are of equal length and area; because, in the one case, the resistance is all in the direct line of motion; while in the second case, it is in directions continually varying, but usually not in the direction of the path of the body. To what extent this difference will be observed will depend upon the form of curve chosen as the generatrix of the surface. One case only has been considered by naval architects, that in which the lines are trochoidal.

It has been found that the best form of hull is one by which the opposing water is swept aside with a velocity smoothly increasing from zero at the instant of contact with the vessel's stem, to a maximum, thence decreasing by a smooth retardation to zero again, at the maximum cross section, and, from that point, falling back to rest at the stern by a similar, but reversed, set of accelerations and retardations. The well-known "wave-line" forms proposed by John Scott Russell are of this class, and are well illustrated in the shape given to the hulls of many fast ships, and, most simply, by the common cylindrical spindle, or "cigar-shaped," craft so often adopted for submarine navigation and nearly submerged torpedo-boats.

The process of wave-making consists in the gradual absorption of energy by the surface layer of particles of water, by friction with the moving particles of air in contact with them, as the latter sweep over the liquid, and the transfer of the energy of the atmosphere, derived originally from the sun's heat, to the ocean or other body of water. The first effect is to cause rotation of minute systems of liquid molecules, and their gradual increase in extent until the circular orbits thus produced become, sometimes, many feet in diameter, and enormous waves, forty, sometimes sixty, feet from trough to crest, and half a mile long, are sent across the ocean at a velocity of thirty or forty miles an hour. Each particle in the mass revolves in a circular orbit, and the succession, as to time, is such as to give the effect of motion of translation, not of the water, but of the form of the wave. In every wave, after each circular excursion, the particle is returned to precisely the point at which its cycle of movement began, its orbit being exactly equal in diameter to the height of the wave from trough to crest.

It is evident that the action of the ship on the water in contact with its sides is

precisely the same as that of a mass of moving air on the surface of water, and that it tends to cause the same motion and the same form of water-surface. Well-formed ships accommodate themselves to this form of contact-surface, the formation of the wave is not interfered with, and the vessel moves smoothly along without producing visible extraneous disturbance; but a badly-formed hull compels the wave-particles to form their orbits between their natural limits, and to cause serious disturbance of the surrounding fluid, at great expense of impelling power. To give best results, minimum resistance and driving power, the form of the submerged part of the ship must fit this natural form of the displacement. It is for this form of displacing body that the resistance due to this form of friction should be calculated. The hull of the craft can then be given the best form for its purpose, and it becomes possible to calculate with approximate exactness and certainty what engine power must be given to drive it through the water at any required speed. The calculation will be readily made for the now standard form of hull, that in which the trochoidal or wave-line is adopted.

The oldest writer on forms of ships who has given any well-defined system of laying down lines was probably the distinguished naval architect Chapman, who proposed to use a system of lines composed of parabolic curves adapted to the intended size and proportions of the vessel. His system was entirely conventional, and consisted in the selection of an index for the parabolic lines to be laid down, such that the curve should "fay in" with the principal dimensions of the hull. Nystrom has recently elaborated this method more completely, and has reduced it to something like a complete system, calculating a set of lines and tabulating both longitudinal and cross-sectional co-ordinates of such curves as are best fitted to produce the various sections of the hull, both for fast passenger transportation and for slow-going freight steamers. Such tables are given in his "Pocket Book," with examples of application. The general formula of parabolic lines is assumed as

$$y = a\left((1 - \frac{x^n}{b^n}\right)^q$$

in which x is the distance of the ordinate y from the "dead flat," and a and b are constants, the latter representing the length of the ship from the dead flat to stem or stern, and the former the half-breadth at the maximum section. By proper selection of values of the indices n and q, ships of full or fine lines are secured. The water-lines consist of parabolas having vertices at the midship section, continuous with other such curves having their vertices at stem and stern. The larger the value of n and the lower that of q, the finer the lines. It is evident that such a system permits the construction of equations for all the essential properties and quantities of the vessel, including displacements and resistances. Such formulæ were obtained by Nystrom, who publishes them with his tables of ordinates.*

* See Journal of the Franklin Institute, 1861-6; Nystrom's "Technological Education and Shipbuilding;" and Nystrom's "Pocket Book of Mechanics and Engineering."

In the equation which has been given as the fundamental equation of the systematic parabolic method of ship-design, the quantities a and b are determined by the dimensions of the ship; the exponents n and q are assigned by the designer according to the requirements of the case in hand, n giving the order, and hence the curvature of the lines, and q being so fixed as to give the desired scale of measurement. The quantity within the parenthesis is always fractional, except for the limiting values of x, when it becomes either 0 or 1; it expresses the ratio between the magnitudes of the ordinate to which the equation is applied and the maximum half-breadth of the ship. If q be increased, n being constant for the time, the lines, as already stated, become finer, and, increasing n with q constant, fuller. Any desired fineness or fulness of lines may thus be secured by proper adjustment of these values.

The great simplicity and plasticity of this modification by Nystrom of Chapman's methods have always seemed to the writer to promise much advantage in the adaptation of these curves to the purposes of modern ship design. While the lines are not trochoidal, they may be made to approximate so closely to such curves that the difference becomes practically unimportant, and the ease with which they may be laid down, and all required quantities estimated, and especially the facility with which the system adapts itself to the production of a complete system of equations for all such quantities, constitute advantages that would seem likely to prove of real value in practice. It has apparently attracted but little attention, and has not been developed to any important extent. Something was done, however, recently, by Mr. H. de B. Parsons, B.S., M.E., then connected with the Stevens Institute of Technology, whose interest in the subject of naval construction, and especially as related to the building of fast yachts, leads the writer to suggest this to him as a matter deserving of study, and it may be allowable to present a part of his work as illustrating the facility with which this system may be developed. It should be said that Chapman was led to the selection of this class of curves for ship's lines by the discovery that a very close correspondence existed between the forms of hull so laid down, and those of the most successful of all known vessels up to his date. Naval architecture dates back to so early a period that a process of trial and error extending over centuries had, even in Chapman's time, produced some very beautiful models, and some exceedingly fast and smooth-running craft. The straight and the hollow lines which have in later times been, the one after the other, considered the best bow lines for fast craft, were used at a period antedating any existing vessels. The former was adopted by Robert L. Stevens as early as 1854, and in building the famous *Stevens Ironclad Battery*, probably after many years of experience on the part of his father and of himself. He used the hollow line on some of the earliest of American steamboats (1827-30).

In illustration of the flexibility of their formula, already given, assume the following values of n and q, then, if $a = 4$ and $\mathrm{I} = 10$, we set:—

Case No. I.	No. II.	No. III.	o. IV.
Value of n ... 1	1	2	2
Value of q ... 1	2	2	1

Then we find, for—

$x = 0, y = 4{\cdot}00$	4·00	4·00	4·00
$x = 1, y = 3{\cdot}60$	3·24	3·92	3·96
$x = 2, y = 3{\cdot}20$	2·56	3·68	3·84
$x = 3, y = 2{\cdot}80$	1·96	3·31	3·64
$x = 4, y = 2{\cdot}40$	1·44	2·82	3·36
$x = 5, y = 2{\cdot}00$	1·00	2·24	3·00
$x = 6, y = 1{\cdot}60$	0·64	1·63	2·56
$x = 7, y = 1{\cdot}20$	0·36	1·04	2·04
$x = 8, y = 0{\cdot}80$	0·16	0·51	1·44
$x = 9, y = 0{\cdot}4$	0·04	0·14	0·76
$x=10, y = 0{\cdot}00$	0·00	0·00	0·00

These are evidently the elements of the lines of vessels about five breadths in length. For the ordinary sailing freight vessel this is a good proportion, or for many yachts; but for the more usual type of steamer for trans-oceanic traffic, the length should be nearly or quite doubled. The curves of which these figures are the co-ordinates have been constructed by Mr. Parsons, and are represented on Fig. 1 (Plate XXXVIII.)

Thus by selecting proper values of n and of q, the waterlines may be made as fine or as full as may be desired. In case No. 1 it is seen that the lines are straight; in case No. 2, we have hollow lines; in No. 3, partly full and partly hollow, the whole closely following the Scott-Russell line, and the trochoid that he would have adopted; while in case No. 4, we get a full line tangent to the middle body at their junction. The last two forms are those which are almost universally used, with more or less modification of the degrees and proportions of curvature, in modern shipbuilding, if the approximations of a purely empirical method can be said to approach any system at all.

The same formulæ may be used for all horizontal section curves above the waterline of the ship, the freeboard surface thus being brought into the most perfect continuity with the wetted surfaces. The hollow line, or its later modifications, may be thus carried up above the load-line to give more perfect action of the vessel in a seaway. Indeed, the pliancy of the formula is so great as to permit its use in describing the most diverse forms, as the common and higher orders of hyperbolas and parabolas, ellipses, the circle, and even the square, and all intermediate forms of curve. For the square, $n = 0$; $q = 1$; for the circle, $n = m$ and $q = \frac{1}{m}$; for the common parabola, $n = 2$ and $q = 1$; and for the hyperbola and ellipse, other values, dependent upon the order desired. Both bow and stern are evidently to be laid down in the same manner, the proportions of length of forward or of after body being first settled upon, and the relative fineness of lines determined.

The same formula can be made to give the cross section curves of any desired fulness, or the reverse, by similar treatment Fig. 1 (Plate XL.) and it is equally easy to get the full middle body of the freight steamer, or the peculiar ogee shape desired in the yacht intended to be easy in a seaway. Here the vertex is taken at the load water-line. The maximum value of y is that of the half-breadth at the section to be constructed, and the value of x, which corresponds to $y = 0$, is the depth of the vessel, D, from load-line to keel.

The integration of the equation

$$A = 2a \int_o^B \left(1 - \frac{x^n}{B^n}\right)^q,$$

or of

$$A = 2a \int_o^D \left(1 - \frac{x}{D}\right)^q,$$

for the water-line sections, or the cross sections, as the case may be, gives the areas of these sections as

$$A = 2a\,B \left(1 - \frac{q}{n+1}\right) + \frac{q\,(q-1)}{2\,(2n+1)} - \frac{q\,(q-1)\,(q-2)}{6\,(3n+1)} + \text{\&c. to the } (q+1)^{\text{th}} \text{ term,}$$

and as

$$A = 2a\,D \left(1 - \frac{q}{n+1} - \text{\&c.}\right)$$

for the two cases respectively.

The values of these areas being thus obtained, it is easy to determine the solidities of the fore and after bodies by laying them down, and, by trial, obtaining a value for n and also for q for the curve of sections so produced, and then treating this similarly, or by the use of Simpson's or other equivalent rules.

The rectification of the curves similarly gives their lengths, and the wetted perimeters of the cross sections are thus obtained. The positions of the centres of gravity and of buoyancy, and any other needed quantities, are similarly determinable as functions of the fundamental equations of the ship.

A vessel being designed, as indicated, by the use of either the parabolic method and Nystrom's tables, or by the application of the wave-line system and the trochoidal curves proposed by Russell, if the form is made such as to give smooth and fair lines and surfaces, it becomes easy to calculate, with very satisfactory accuracy, the resistance of the ship and the engine power required to drive the hull through the water at any designated speed. The two systems produce vessels of such smooth form, and so nearly alike in their action in moving through the water, that the approximate formula of Rankine may be used for either. This formula may be derived in the following manner:—

In every fair-lined, well-formed ship the wave-making energy, if the ship is driven at or below a speed for which the lines are properly drawn, may be assumed to be too

small to be considered, and the resistance as practically due entirely to friction. Suppose a wave having a period due to the speed of the ship to have fitted upon it a wave-shaped solid, and the latter to move along with the wave, the frictional resistance would be that due to the area of that solid moving over the surface of water at the assumed speed. To obtain a measure of this resistance, Rankine determined the mechanical work done while overcoming friction during an elementary period of time, $d\,t$, and dividing that work by the distance through which the solid, as a whole, moves in that time.*

The intensity of this resistance per unit of area is the quotient of work done divided by distance traversed. By a simple process of algebraic analysis, based on this method, the expression for the total resistance is found to be

$$R = A\,L\,B\,(I + 4 \sin^2\theta + \sin^4\theta) \times V^2;$$

in which equation θ is the angle of greatest obliquity of the curve, A is a constant multiplier, L the mean wetted girth of the surface exposed to friction, L the length, and V the speed of the vessel. The *power* demanded to impel a ship is thus found to be the product of a constant to be determined by experiment, the area of the wetted surface, the *cube* of the speed, and the quantity in the parenthesis, which is known as the "co-efficient of augmentation." The product of this last quantity by the length and breadth of wetted surface is the area of a surface of cylindrical form similar in section to that of the middle body of the ship, and exceeding the length of the latter by the amount indicated by the magnitude of this co-efficient. The last term of the co-efficient may be neglected in calculating the resistance of ships, as always too small, in cases to which the formulas apply, to be practically important. In applying the formulæ, the mean of the squares of the sines of the angles of maximum obliquity of the water-lines is to be taken for $sin^2\,\theta$, and the rule then will read thus:—

To obtain the resistance of a ship of good form, in pounds, multiply the length in feet by the mean immersed girth and by the co-efficient of augmentation, and then take the product of this "augmented surface," as Rankine termed it, by the square of the speed in knots, and by the proper constant co-efficient selected from the following:—

For clean-painted vessels, iron hulls	0·01
For clean-coppered vessels	0·009 to 0·008
For moderately rough iron vessels	0·011 +

the result will be approximately and very closely the resistance in pounds.

The net, or effective, horse-power demanded will be quite closely obtained by multiplying the resistance calculated, as above, by the speed in knots and dividing by 326. The gross, or indicated, power is obtained by multiplying the last quantity by the

* Miscellaneous Papers, p. 491; Phil. Trans., 1863; Trans. Inst. Nav. Archts., 1864; Treatise on Shipbuilding, 1864.

reciprocal of the efficiency of the machinery and propeller, which usually should be above 0·6. Rankine uses as a divisor in this case 200.

The form of the vessel, even when designed by skilful and experienced naval architects, will often vary to such an extent as to cause the above constant co-efficients to vary somewhat; and the range of variation is found to be from 0·8 to 1·5 with the familiar types of steamers. The rule of the originator of the "wave-line theory" is to give the fore-body a length equal to, or exceeding, that of the after-body; and he considers that it may be a half longer than the latter with advantage. His rule for the after-body is: Take three-eighths of the square of the speed in knots for its length in feet. Also, to find the best speed for a given length of after-body: Take the square root of two and two-thirds times the length in feet, and the speed is given in knots. The sum of these lengths usually is less than the proposed full length of the ship, in which case a straight middle body is introduced. This rule is apparently not exact, however, as it is found that the power demanded in the propulsion of vessels having forms quite different from, and fuller than, those produced by the wave-line may be less than that calculated as above.

A convenient form of the equation just given is the following:—

$$HP = \frac{S\,V^3}{20{,}000};$$

in which S is the augmented surface in this expression for iron vessels. Investigations made upon iron steamers of moderate size, and of good reputation as economical in their absorption of power, in cases in which American constructions of coasting steamers have been considered, show that, though much fuller than the wave-line theory would dictate, and although having much less easy lines, apparently, the co-efficient often exceeds that given for trochoidal ships. The ss. *City of Columbia* was found by Mr. H. C. White to illustrate this case.

The examination made by Messrs. Elliott and Lieb, then of the Stevens Institute of Technology, of the speed and power of the *Mary Powell*, a famous Hudson River steamer, having a hull of wood, coppered, and making a speed exceeding, at times, twenty miles an hour, indicated the value of the co-efficient for that craft to be 23,500. The *Mary Powell* is 280 ft. long on the water-line, 33½ ft. beam, and of 6 ft. draught. The displacement is 30,000 cubic feet, or 757 tons. The engine, a beam engine of the common river-boat type, works up, at times, to nearly 2,000-horse power and weighs 210 tons. The lines of the hull are approximately trochoidal, but the hull is broad and shallow. The augmented surface is very nearly 8,000 ft., and the co-efficient of augmentation is 1·18. The engine has a steam cylinder 72 in. in diameter, and 12 ft. stroke of piston, and is fitted with a Stevens valve-gear, cutting off at 0·487 stroke. The wheels are 31 ft. in diameter and 10½ ft. face, immersed, at load draught, 3½ ft. The slip, according to Isherwood, is 16·37 per cent. The boilers are return tubular, and have 154 square ft. of grate surface and 4,700 ft. of heating surface, beside superheating

surface in the steam chimney amounting to 675 square ft. Coal is burned at the rate of 40 lbs. per square foot of grate, the draught being produced by fan-blowers. With a mean effective pressure of 24·4 lbs. per square inch in the steam cylinders a speed of 19·5 miles has been attained, with an indicated power of 1,570 H.P. These particulars are not all relevant to the purposes of this paper, but they are given more fully than they would otherwise have been because of the fact that the performance of the *Powell* has been such as to make her, probably, the most famous craft of the type in American waters.

The co-efficient was obtained from existing data, mostly collated by Chief Engineer Isherwood, of the United States Navy, for the purpose of applying it to another steamer, the *Sylvan Dell*, on board which Messrs. Elliott and Lieb were proposing to carry out a similar investigation, but without being able to secure certain essential data. This was a smaller craft, 178 ft. long on the water-line, 25 ft. beam, and draught 5½ ft. The displacement was 10,690 cubic ft., or 10,960 ft. with all appendages. The co-efficient of augmentation was 1·203, and the augmented surface 4,500 square ft. The engine weighed 57, the boiler 21½, and its water 22½ tons; attachments 10½, engine frame keelsons, &c., 16, and the water carried in tanks 23 tons: a total of 150 tons. Engine and boiler were of the same types as the *Mary Powell*'s. At 25 lbs. steam, by gauge, and a vacuum of 28 in., 25·4 revolutions per minute gave 686 H.P. and a speed of 17·3 miles, or 15 knots an hour. Applying the co-efficient of the *Powell* in the calculation of the probable speed, gives 15·3 knots. The difference is probably largely due to slip of paddles, which amounted to 20·5 per cent. in the case of the *Sylvan Dell*. Applying Rankine's rule, multiplying the square of the cube root of the displacement by the cube of the speed, and dividing by the indicated H.P., we obtain a measure of performance in a co-efficient which that writer states is from 200 to 260 in good examples. In the cases of these vessels, the investigators found this constant to be, for the *Powell* 290, and for the *Sylvan Dell* 250. Thus it is seen that the *Powell* excels, while the *Dell* about equals, the best steamers known to the author of the rule. The larger the co-efficient, obviously, the better the performance.

The *Powell* was built by Mr. M. S. Allison, of Jersey City, in the year 1861, and the engines by Messrs. Fletcher & Harrison. The hull was lengthened 20 ft. in 1871. The *Dell* was built by Messrs. Lawrence & Foulkes, of Greenpoint, Brooklyn, and the engines by Messrs. Fletcher & Harrison also. The two boats have remarkably similar forms, and they well represent the standard, as it may be termed, in recent construction of vessels of this class. Their wide departure from the forms of deep sea-going craft, from which the rule adopted in calculations of resistance and power was deduced, is taken as an illustration of the fact that the trochoidal form, or even the general proportions given by the wave-line theory, may be widely departed from, if only the lines be fine and fair, without loss of efficiency, or even with advantage. So far as the writer is aware, it is not the habit of the best builders to attempt the fineness of stern, far less of

bow, that the Russell system would dictate as best. In fact, it is almost invariably the fact that the bow is made much shorter and fuller than the stern, and it is also the almost invariable custom, on fast as well as on slow ships, to make the after-body much shorter than the above rule would dictate.

It will at once be seen, on reflection, that the form proposed by the wave-line theory is simply an expedient by which the head resistance is reduced to an inappreciable quantity, and that the calculation of the remaining element of resistance, that due to friction, is thus made easy and accurate. But it is also easy to see that a slight reduction of length, or a slight increase in fulness of line, such as would make head-resistance perceptible, might decrease the friction, by its reduction of area of augmented surface, to a greater extent. In fact, it is certain that there exists, somewhere between the proportions given by the wave-line construction and those of the old-fashioned bluff-bowed and full-sterned ships, a golden mean at which the sum of all resistances is a minimum. The proportions of ships are usually stated in the ratios of length to breadth ; but it is evident that this is only correct in cases in which the hulls compared have similar forms, as the length of bow and of after-body are, according to the accepted theory, functions of speed proposed, and not of length or breadth or size of ship. Experience, as well as approximate theoretical determinations, would indicate that, for the common forms and sizes of vessel, a length equal to about seven breadths is not far from the best ratio for sailing vessels, and ten to one for screw steamers, in which latter case the location and action of the propeller is an important element in the problem. The *Sylvan Dell* is just seven to one ; the *Mary Powell* is something over eight to one ; and the most successful Transatlantic screw steamers are about ten to one. But the precise proportion which gives maximum efficiency has never yet been determined, either by experience or direct experiment, and it is probable that it may be a long time before it is settled.

Some twenty years ago, while the writer was still in the Navy as an officer in the Engineer Corps, and was stationed at the Naval Academy, where the position to which he was detailed as A. A. Prof. Nat. & Exp. Phil. permitted occasional thought beyond the limits of daily duties, and while studying the subject here again taken up, it occurred to him that it might be possible to get a hint as to the best forms of ships by studying those which Nature had produced, after a period of trial and evolution by survival of the fittest, the length of which is beyond our computation or imagination. It seemed to him very probable that the fastest of fishes must have the best possible proportions of form, and shape of line, that such small craft could possibly be given. It seemed further possible that, by studying the lines of fishes, some general law might be traced throughout a somewhat wide range of size, and thus a hint obtained as to whether the forms so determined as best for speed were subject to modification to any important extent with increase of size. Should the latter not prove to be the case, it

was concluded that the result of the investigation might, perhaps, give a clue to the best forms of line for small vessels, even if not for all crafts, large or small. A piece of apparatus was planned, somewhat similar in its principles to the *conformateur* used by the hatter in finding the shape of the head of his customer, by means of which to obtain a reproduction of the form of cross section of the fish, and it was intended to make a very complete investigation; but a change of location and occupation interrupted the work before the preliminaries were completed, and the opportunity was lost.

This research had, however, been undertaken at a much earlier date, and unknown at the time to the writer, by John S. Enys, Esq., F.G.S., &c., who contributed to the Transactions of the Royal Cornwall Polytechnic Society, and published in *Hunt's Yachting Magazine*, August, 1856, an account of his investigation, with illustrations, carefully drawn to scale, of the fish and the lines examined. Mr. Enys gives very few particulars of his work, contenting himself with the presentation of his drawings showing the lines of the fish studied, including those of the "porbeagle," or mackerel shark, the common mackerel, and the trout. These plates are here reproduced (Plates XXXVIII., XXXIX., and XL.). Mr. Enys opens his paper with the remark that it has long been thought that the lines of a fish are applicable to a boat, but that these lines vary among each other quite as much as do those of boats. The forms of cross section of the three selected for reproduction differ greatly, the shark (Plate XXXVIII.) having a circular section and the mackerel and trout (Plate XXXIX.) oval forms. They would require some modification to adapt the lines to ships, since the latter are partly out of water; while the fish is intended for submarine navigation entirely. He would separate the tail from the body in laying down these lines, on the ground that it is a distinct instrument, and the point of separation selected is that at which the two lines, on opposite sides the principal horizontal longitudinal section, intersect the direct line of the spine, when the fish swings the tail to its extreme range on either side when swimming. The writer would consider it more correct to take the point in the spine at which the natural curvature of the body cuts it, irrespective of the tail, as that at which the hull should be considered as terminating. This would make the after-body of the fish some fifty per cent. longer, usually, than Mr. Enys makes it, and more in consonance with other considerations already given and to be given. In reproducing his illustrations, this modification of the deduced curve of sections has been made by the writer.

The largest transverse section is taken, as is customary, as the "midship section." The middle body is considered to include all transverse sections greater in area than four-fifths the midship section. The points of junction between it and the ends are marked by heavy ordinates, as are those at which the hollow line begins. Chapman's curve of displacements (Plate XL.) is used to exhibit the variation of transverse sections from stem to stern. The three fish here studied are very powerful and fast swimmers.

The investigation of the forms of fishes familiar to seamen on the coast of the

United States, which had been planned by the writer, remained unprosecuted until, in the year 1883-4, Mr. H. de B. Parsons—then, as already stated, a graduate student at the Stevens Institute of Technology—an expert yachtsman, who became much interested in the subject as presented to him by the writer, undertook to secure further experimental knowledge of the forms of the faster American salt-water fishes. The work was interrupted before it had been carried out to the full extent planned, but some interesting facts and data were obtained.

The fish selected for examination were all sea fishes, with a single exception—the trout—and, with the exception of the latter, were measured up as they came fresh from the water. The measurements of the trout were taken from a plaster cast belonging to Mr. Eugene G. Blackford, of New York City, U.S. Fish Commissioner, and a well-known naturalist, who very kindly permitted its use for this purpose. These fishes were :— The lake trout, the Spanish mackerel, the pollock, the Restigouche salmon, the blue fish, the striped bass ; six in all, and all graceful, fast, and very powerful. The curves of cross-sections were laid down to form a set of Chapman's curves on half-breadth plans, the measurements being taken at intervals of one inch along the spine of the fish. The curves so obtained were all laid down to one length, 10 in., for the purpose of easier comparison. The body is considered here to be divided into a fore-body and an after-body only, as it was observed that no one of them had any straight middle-body, all tapering both ways from the maximum, or midship, section. The following are the reported dimensions :—

Name.	Actual.	Reduced.		
	Length.	Section.	Fore Body.	After Body.
		Square inches.	Inches.	Inches.
Trout	12·28	2·04	3·82	6·18
Spanish Mackerel	16·00	1·61	3·76	6·24
Pollock	13·2	2·31	3·52	6·48
Salmon	30·00	1·77	3·62	6·38
Blue Fish ...	25·00	1·88	3·52	6·48
Striped Bass ...	25·00	2·75	3·50	6·50
Average, reduced		2·06	3·62	6·28

The areas evidently bear the relation to lengths, L—

$$L^2 : 100 :: \text{Act. Area} : \text{Scale Area.}$$

The figures which are reproduced in Plate XL. represent the curves of displacement of all these fish, and may be compared with those already given as obtained by Mr. Enys, and with the average curve Plate XL., which is the mean of those given for the shark, mackerel, and trout. On these curves the scale areas are represented by one inch of ordinate per square inch of section on the reduced scale. The ordinates are numbered from head to tail, the head being on the left and the tail at the right of the figure. In addition to the curves for each fish, the curve obtained by plotting the average of all is given as the last of this series, on the same scale as the others, ten inches total length, and one inch of ordinate per square inch of reduced cross section. In spite of the very considerable differences in length, and the observable, but less marked, differences of general proportions of the fishes studied in this collection, it is interesting to note that the proportion of fore and after body to each other, and to total length, is very nearly the same in all; and the average curve has, therefore, more value and significance than it would have otherwise had. The equation of this average curve, as found by Mr. Parsons, is, for the fore-body:—

$$y = a\left[1 - \left(\frac{x}{1}\right)^{1\cdot75}\right]$$

and for the after-body:—

$$y = a\left[1 - \left(\frac{x}{1}\right)^{1\cdot4}\right]^{1\cdot8}$$

the symbols being taken as before in this paper, *i.e.*, y being the measure of the ordinate at any assumed point in either fore or after-body, and x the distance from that point along the axis of abscissæ to the midship section; while 1 is the total length of the fore or after-body, and a is the maximum ordinate at the midship section. In other words, a is the area of the midship section and y is the area of a cross-section at the point designated by the distance x from the midship section.

Studying the data in detail, it is seen that the proportion of length to breadth for the several fish, taken in the order in which they are given in the table of dimensions, runs thus:—Trout, 7 to 1; Spanish mackerel, 8 to 1; pollock, 6½ to 1; salmon, 8 to 1; blue fish, 7 to 1; striped bass, 6 to 1; and the average is very closely seven to one. The faster the fish the higher is the ratio. It will also be observed that the slower fishes have more nearly straight bow-lines on their curves (see salmon, blue-fish, and bass, Plate XL.), and the fastest have bow-lines of greater curvature; while the lines of the after-body are, on the curve of sections, almost straight for a large proportion of their lengths in the cases of the fastest fishes—the Spanish mackerel and the blue fish—and are more hollow in the curves of the slower pollock and bass. The average curve (Plate XL.) exhibits a full convex bowline, and a hollow, concave run. The fast fishes approximate the shape of the cylindrical spindle in their forward, and a leaner shape in their after-bodies. It would seem that the meaning of the latter deviation from the wave-line is, that it is found advisable in fishes, as in screw steamers, to secure a very lean after-body and fine run, in order that the propeller may be carried well aft, beyond the influence of the impeding

eddies, and to permit the currents of water to close in smoothly, and so completely, that a tendency to the production of resistance by loss of pressure and negative slip may not arise. It will be noticed at once, that no one of these cases exhibits hollow water-lines for the entrance, or even the straight bow which is becoming common in yachts, and is occasionally seen in larger craft. Even the pollock has a straight line, substantially, in its curve of displacement forward the "dead-flat," or midship section. How much this may be due to the necessary conformation of the jaws and the muscles operating the pectoral fins, it is impossible to say; but the fact that convexity of the fore-body is universal, and none the less in fishes swimming almost entirely by means of the tail, would seem to indicate that the ideal bow-line is full and convex throughout, and more so than in the ideal wave-line form, the cylindrical spindle.

Studying these forms more minutely, it is to be noticed that the variation of shape here observed among all the various cases examined is not one which is at all related to size, but rather to character of the work to be done. The lake trout, one foot in length, has substantially the same form of curve as the salmon of two and a half feet length, although slightly different in its proportions of length to breadth. The Spanish mackerel, sixteen inches long, copies the curve of the blue fish nearly double its size. The pollock, however, a comparatively slow fish, and nearly of the same size as the other small fishes examined, has quite different lines; it is a fish of broader beam, but, curiously enough, of more nearly hollow lines than the faster forms with which it is compared. Another interesting and possibly important fact which comes out in this comparison is, that the position of the "dead-flat," the maximum cross-section, is substantially the same in every case; it is situated at between 36 and 40 per cent. of the total length from the stem, and its location has no apparent relation to the speed of the fish. Its position is almost absolutely identical in the bass and the blue fish, a trifle further aft in the salmon, which latter is identical in this point with the trout, and in the pollock and Spanish mackerel it falls a little further aft still. It may evidently be taken as a rule that the dead-flat section is, in fast swimming fishes, placed so as to divide the length of the whole body in the proportion of three and a half to four parts fore-body, and six and a half to six parts after-body, the variation being rarely more than 2 or 3 per cent. The forms produced by the process of evolution of natural fast-swimming craft have fore-bodies which not only do not have a greater length than the after-body, much less 50 per cent. greater as the wave-line rule would make them, but quite reverse the rule, the after-body being one-half longer than the fore-body.

Comparing, finally, the lines of these comparatively small craft with the larger examples taken from Mr. Enys' researches (Plates XXXVIII. to XL.), the shark, the latter being as much larger than either of the fishes studied here as the largest of the latter exceeds in size the smallest; and noting the changes, or rather the permanences, of form, as we proceed from the trout and pollock of one foot length, through the intermediate sizes of the blue fish and bass of more than twice their length, and up to

the shark, whose length is two and a half times that of the last-named, and six times the length of the first, we find one general plan to run through them all, and one set of proportions to distinguish all the fast-swimming fish. The lines are evidently similar, the method of parting and leaving the water behind exactly the same, and the proportion of fore to after body substantially alike in all. It would not seem rash to conclude that it may be quite as likely that these proportions may be preserved, and these lines retained, in still much larger fish, and to be correct for small, if not for very large, yachts and other vessels. A very interesting, and to the writer particularly striking confirmation of this conclusion was given in the following incident. The writer was interested in the design of a small craft for naval purposes, which was intended to be as powerful and fast as the present state of the art of naval construction should permit. The lines were laid down and drawings made by Mr. William Cowles, of New York, who, before deciding upon the form or proportions of the hull, studied the lines and performance of every extraordinarily successful steam vessel that he could find. After careful comparison, and drawing his own conclusions as to the most satisfactory lines for his purposes, he drew what he believed likely to be as good a design for a swift steaming boat as could be made at the present day. The plans were completed and brought into the office of the writer, as it happened, just after the work which has been above described was completed, and the report laid upon his desk. A comparison of the designs for the new steamer with the lines of the fast-swimming fishes showed a substantial accordance in all essential respects, and the location of the maximum transverse section was identical with that found, as above, for the forms designed by Nature. As the rule of the wave-line construction fixes a general form of hull and character of curve for all vessels, whatever their size, and gives a fixed relation of length of fore-body to that of after-body ; so it would seem natural forms, among the fast-swimming fishes, have similar general relations, irrespective of size ; although the rule followed in the production of the natural form is not that prescribed by the most generally accepted authority among naval architects. It is to be said, however, that notwithstanding the fact that the wave-line theory is probably very generally admitted, designers of the most successful ships have by no means followed it closely in actual work. They have approximated more closely to the natural than to the conventional form.

How far this study of the forms of fishes can have useful results in directing us to correct forms for the hulls of steam vessels is a matter in regard to which a difference of opinion is very likely to exist. That the forms of the fast swimmers among the deep-sea fishes are substantially the best that can be given them, for their purposes, will probably not be a matter in relation to which serious discussion will arise ; they are probably the best possible. That the best form for a small fish is substantially correct for a large one has been seen to be probably beyond doubt, as well as that the forms of all fast fishes are similar in general proportions as well as in the shapes of their curves

of displacement and of water-line sections. But that a form which is best for a submerged craft is best for one floating on the surface, subject to the buffeting of the sea, and to pitching and rolling due to such action, is not so certain; or that the underwater portions of the hull should be alike for smooth and for rough seas. The writer is inclined to think, however, that the submerged parts of any deep-sea craft, considered as a form intended to offer minimum resistance to its impulsion, should not be far different in the two cases; this is undoubtedly not true of the freeboard. That a sailing vessel should have a different shape from a steamer, and especially from a screw steamer, is certainly the fact also; and that the latter should have a longer and leaner run than the former is obvious, if such difference is admitted at all. But that the general principles governing the parting of the water by the bow, and its return under the stern, must be the same, approximately at least, for all, would seem sufficiently evident. The fact that a sailing vessel, when doing her best in an average—say topsail—breeze, must always lie over to leeward somewhat, indicates that the relations of proportion studied for that case must be such as will permit the action of the moving hull to be approximately such as the general laws would dictate, whether on even keel or at an angle, and the conditions of rolling of the steamer would also lead to a somewhat similar conclusion for the general case.

Fast-sailing yachts, curiously enough, seem to precisely invert the principles above derived. The very fastest yachts the world has yet seen have their maximum sections at points not far removed from 60 per cent. of the total length measured from the bow. Thus, the following table gives the principal dimensions of a number now celebrated for their speed:—

PROPORTIONS OF FAST-SAILING YACHTS.*

Parts of the Vessel.	Mayflower.	Puritan.	Priscilla.	Atlantic.	Galatea.
Length over all	100	93	95	95·1	100
Length on waterline (ft.) ...	85	81·1½	84	83	86
Beam (ft.)	23·6½	22·7	22·4	23·2	15
Depth of hold (ft. and in.) ...	8·10	...	8·7	10·6	13·3
Draught (ft. and in.)	9·6	8·5	7·9	9·3	13·6
Area of mid section (ft.) ...	82	82	86½	102	...
Mid section from bow ...	0·61L.	0·58L.	0·60L.	0·66L.	0·60L.
Mast, deck to hounds... ...	63	60	59	63	...
Topmast (ft.)	46	44	48	47	...
Bowsprit, outboard	38	38	39·5	38	...
Boom	80	76	77	76	...
Gaff	50	47	48	48	...
Tons of inside ballast ...	11	13	...	32	...
Tons of outside ballast ...	37	27	45	33	80
Displacement (tons)	110	105	112	108	...
Sail area by rule	...	7,370	7,381	8,012	...

* Mainly from *Forest and Stream*, August 26, 1886.

In every case except that of the *Galatea* the length is less than four times the breadth of beam, while the latter is but six to one; and this discrepancy is partly, if not wholly, compensated by her immense depth as compared to beam. In every case reported, also, the "dead flat" is 0·58 to 0·66 of the length from the bow. If we compare the square root of the product of draught and beam with the length of load-line—probably the best method of comparison of such different forms—it will be seen that the proportions, in the best examples of good designing, as gauged by yachtsmen, run about six to one for the larger craft, as in the *Mayflower* and the *Galatea*, both of which are precisely of this proportion. The smaller the craft, as a rule, among yachts, the broader the model. This fact may be a consequence of the necessity of considering stability more carefully in the smaller boats than in the larger. Here are the dimensions of five small craft:—

PROPORTIONS OF SMALL YACHTS.

	Length over all.	Beam.	Draught.
	Ft. in.	Ft. in.	Ft. in.
Sadie	50·06	16·07	5·09
Shadow	36·00	14·08	5·04
Orion	49·07	15·02	5·03
Nepenthe	45·00	15·00	5·06
Julia	80·00	20·00	7·01

The proportions of our recent American sailing yachts were original with our Scandinavian ancestors. Thorstein, a progenitor of the writer probably, sailed a craft which may be represented in proportions by that recently discovered (1879) at Christiania Fjord, in Norway, and which had the following dimensions :—

Length on load-line	73 ft. 3 in.
Breadth of beam	16 ft. 7 in.
Depth, keel to gunwale	5 ft.
Area of midship section	24 sq. ft.
Displacement	28·5 tons.

We do not know the draught of this boat; but the proportion of the square root of the product of depth and beam to the length on the load-line is one to eight. The shape of the craft was very fine, in bow and run; and the hollow bow which was supposed by many to have been original with George Steers and seen in the famous *America*, designed by him for Commodore Stevens, was beautifully illustrated by the war vessel of the Northman, as it is, and has been for centuries, by the Arab "dhows," and by Phœnician vessels of still earlier date. The long, fine, hollow, bow-line is thus handed down to us by the Vikings, and by the old yachtsmen of prehistoric times.

The comparatively short after-bodies of sailing craft may be due to a process of shortening up to a minimum allowable length, such as is illustrated in steamers and in fishes by the shortened fore-body. At the beginning of the present century, as appears from the statements of the historians of yachting, the "cod's head and mackerel's tail" represented the prevalent principles of designing; but the long bow and hollow lines began to come in about 1825 or 1830. It seems probable that for sailing craft—and, it must be added, very possibly for all forms intended to move along the surface of the sea—the results of ichthyological evolution of fast shapes should be taken, perhaps, as but provisionally applicable to the production of the best forms for speed. That a radical difference is involved in the conditions affecting the steamer and the sailing craft seems perfectly certain.

The deductions which may be drawn with some degree of probability, if not with absolute certainty, from this comparison of natural with artificial constructions for fast swimming, seem to be capable of summary as follows :—

(1) As to the general principles governing the resistance of bodies moving through the water, it may be stated as certain that the head resistance is a minimum when the length of fore-body is such that it shall part the water with minimum disturbance of its surface, and that the wave-line theory provides a rule by which this minimum resistance may be secured ; that the minimum frictional resistance is met when the surface exposed to rubbing, multiplied by the square of its velocity, is a minimum ; and that the total resistance is a minimum when the sum of these two constituent quantities is a minimum. In other words, to secure least wave-making resistance, the ship should have an elongated form, with hollow lines, and such proportion of length to breadth as the wave-line theory would indicate : to obtain the least possible resistance by friction of the water on the sides of the hull, the latter must approach the sphere or hemisphere in shape : to give the lowest possible total resistance, the form must be something between these two extremes, approximating to the former or the latter more closely as the speed is greater or less ; or, in other words again, the proportion of length to breadth increasing as speed increases. The higher the speed proposed, the longer the ship.

(2) The proportion of fore-body to after-body will be affected, and exactly determined, by the method of parting and of restoring the divided water. As the separation is effected by the power of the ship's engines, and the restoration is caused by the force of gravity, and its rate is limited by the acceleration of gravity, it would seem from these considerations, as well as from observation of the best forms for speed, whether natural or artificial, that the after-body, for high speeds at least, should be longer than the fore-body.

(3) The character of the lines to be adopted remains a matter of some uncertainty. If the requirement be simply that the water shall be parted with an accelerated motion, shall come to rest at the middle body, and be restored to its place after the ship has passed with a regular retardation, the lines must be of the kind known as wave-line or trochoidal lines. If the specification be that the total resistance, wave-making and frictional, shall be a minimum, the form thus designed must be shortened up, and the character of the lines may be changed. Experience and observation of the natural form indicate that the curve of displacement for the forward body should be a full line, instead of hollow, as when made on the wave-line system. The lines of the after-body are determined, in part, by the considerations above stated, and also by the action of the propelling instrument, are thus drawn out into a longer and hollower curve, and are more nearly, if not becoming actually, trochoidal. The modern screw steam yacht, with straight bow-lines and fine run, most nearly of usual ship-forms, illustrates this ideal form. The tail of the fish and the screw of the steamer resemble each other as propel-

ling instruments very closely; and the faster the motion of the former, the more closely is the movement of its propeller confined to the extremity, the more nearly does it resemble the latter in its method of operation, and the more exact are the indications, thus derived, of the best form for fast ships.

(4) The fact that the best examples of recent naval architecture, and the most perfectly formed of fishes, for fast movement through the water, have alike a proportion of length to breadth of about eight to one, and that all sizes of fish and of craft, intended for speed purely, have a proportion of fore-body to after-body almost invariably and exactly of seven to thirteen, may probably be taken as indicating a strong probability that such proportion is that which makes total resistance a minimum, for all sizes and perhaps at all speeds, when the propelling instrument is at the stern. Where there is no middle body, as probably in most cases in which the hull is designed for speed simply, the fore-body is 0·35 to 0·40, and the after-body 0·65 to 0·60 of the length of the ship.

(5) The forms of ship best for securing maximum speed with minimum power are evidently subject to modification, in the direction of increasing fulness, for all cases in which the problem is modified by the introduction of any commercial consideration, or the necessity of obtaining greater handiness. In even the fastest vessels such consideration must come in, in all actual cases, and the more as the question becomes more and more one of economy in other directions than that of power. It is thus that in freight traffic at moderate and low speeds the straight middle body is invariably brought in. It is possible that even the animal economy thus modifies the forms of the animate craft that we have here studied.

When, by the processes of evolution of forms of maximum efficiency, of adaptation of size to route and work, and of machinery of maximum power and economy of fuel with minimum weight, such as are now in progress, and doing such effective work, the steam vessel and the sailing craft of the world become as well fitted to their various purposes as are the forms of their prototypes among the fishes, we may expect that the possibility of enormously increased speed and carrying power with greatly reduced cost in power, steam, and fuel, and money will be found vastly more apparent than they to-day appear to the most sanguine of engineers and naval architects. The forms of ships, both sailing and steaming, are probably approximating rapidly to the perfect shape that should crown such a process of development; we are gradually reducing the cost of power in steam and fuel consumed, and have already produced the horse-power on less than 1½ pounds of coal per hour; and the weights of marine machinery have been reduced until Pole and other far-seeing engineers are discussing the possibility of the application of that motor to the propulsion of balloons or other aerial machines. The Herreshoffs have brought the figure to 10 pounds per horse-power for their engines, and 40 pounds for their boilers and fittings; while the weight of water is but 5 pounds per

horse-power developed—a total of 55 pounds, and even this figure has, in at least one case, been bettered. Thornycroft and Yarrow, and other builders abroad, are doing equally well in this direction, and the prospect of a sudden and very considerable increase of speed and efficiency in sea-going vessels seems to the writer one of the most visible signs of the immediate future. It may not be too much to expect that some of the methods outlined in the above paper may prove useful in forwarding this advance.

A NEW METHOD OF USING PAPER SECTIONS FOR THE DETERMINATION OF CROSS CURVES OF STABILITY.

By John H. Heck, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

Some experiments which have recently been made, appear to show, that the data for the construction of cross curves of stability can be obtained by the aid of a paper model and a light balance.

The results of the trials on the models of three vessels of different type are given at the end of this paper, from which it will be seen that the difference between the values of the righting arms given by the apparatus, and those taken from cross curves which have been calculated by Mr. Denny's scientific staff, varies from nought to ·17 of a foot.

The models tried were made of oil-paper, such as is in ordinary use with letter-copying presses. They consisted of about twelve pieces, which were cut to the form of the vessels at intervals of about one-twelfth the length.

In order to save time, and to ensure that the centre lines of the various sections should coincide when joined together, the following method was used:—

Each section had two small square holes cut out, these holes exactly coinciding with two projecting pins, or dowels, which were fixed to a metal plate. After the sections were cut, they were coated with ordinary spirit varnish, placed over the pins, and thus the whole were kept fair to each other and rapidly and accurately joined together.

One of the square holes was located in the assumed position of the centre of gravity of the vessels, and was utilised to fix the model to the apparatus. The models, when made, were found quite impervious to water.

The apparatus, which Mr. A. H. Wilson, of Messrs. Hall, Russell & Co., was good

enough to make for me, consists of a straight-edge A Fig. 1 (Plate XLI.), and two tee-squares B and C.

The straight-edge is suspended upon knife-edges at its centre, and works upon two small hardened steel plates, which rest upon supports over a tank.

At each end of the straight-edge there is a small knife-edge bar E for suspending scale-pans F and H.

The models are fixed to the tee-square B by a small bolt, which passes through the hole which is located in the assumed position of the vessel's centre of gravity.

When the models are immersed in water the tee-square B is also immersed. This would, of course, affect the result. The tee-square C, however, being similar and exactly at the same distance on the other side of the fulcrum, also goes into the water, and therefore neutralises the action. For the same reason, a bolt similar to that used for attaching the model to the tee-square B is also fixed to the tee-square C.

In order to determine the righting lever for any angle or displacement the following must be done :—

(1) Fix the model to the tee-square B, and turn it to the desired angle, as shown in full lines in Fig. 1.

(2) Find the weight necessary to be put into the scale-pan H, in order to balance the weight of the model.

(3) Find the same also when the tee-square B is turned half-way round, so that the model comes into the position shown by dotted lines in Fig. 1.

(4) Pour water into the tank until the model is immersed to any desired depth, put into the scale-pan H the weight necessary to balance the model, and into the scale-pan F weight to balance the upward pressure of the water, let this latter weight be called W ; then

W × by its distance from fulcrum = water displaced by model × by its distance from fulcrum.

In order to determine the displacement, turn the tee-square B half-way round, back to its original position, so that the model comes into the position shown in full lines, Fig. 1., put into the scale-pan H the weight necessary to balance the model, and into the scale-pan F weight to balance the upward pressure of the water ; let this latter weight be called $\overline{W}$, then $W + \overline{W}$ = water displaced by the model, consequently the righting lever and the displacement is determined, as the distance of the centre of gravity of the vessel from the fulcrum is a constant known quantity.

By adding more water and finding the two weights necessary to balance the upward

pressure of the water when the model is in the two different positions, the same can be found for any greater displacement.

By a similar way the righting levers and the corresponding displacement can be found for any angle.

A check-test can also readily be made by removing the weight out of the scale-pan F and balancing the upward pressure of the water, by taking out weight from the scale-pan H; the weight so taken out should then equal that which was found necessary to be put into the other scale-pan.

The displacement of vessel, corresponding to each ounce of water displaced by the model, can at once be found by the balance; by finding the water displaced by the model at the upright position, and when immersed to the load-draught, for

> Displacement of actual vessel at load-draught ÷ by weight of water in ounces displaced by model equals .... tons of displacement to each ounce of water displaced by model.

The time required to make a model and to find three spots in the curves for six different angles, together with a check-test, is about fifteen hours.

An Appendix is added, with full directions for making models.

S.S. *A*———.

RIGHTING LEVERS (NEGATIVE).

Angle.	By Machine.	By Calculation.	Difference.	Displacement.
	Feet.	Feet.	Feet.	Tons.
15	—1·287	—1·28	·007	1,642
15	—1·59	—1·63	·04	3,650
30	—1·8	—1·81	·01	1,190
30	—2·62	—2·7	·08	2,255
30	—2·89	—2·8	·09	3,454
45	—3·2	—3·39	·09	1,344
45	—3·51	—3·34	·17	1,972
60	—4·85	—4·75	·1	934
60	—4·17	—4·14	·03	1,500
90	—6·5	—6·54	·04	1,600
90	—6·8	—6·66	·14	2,412

Vessel, 285 ft. × 35 ft. × 26 ft. Model made to a scale ¼ in. = 1 foot.
Type, flush-deck vessel. Weight of Model, 6·8 ounces.

P.S *B*———.

RIGHTING LEVERS.

Angle.	By Machine.	By Calculation.	Difference.	Displacement
	Feet.	Feet.	Feet.	Tons.
15	1·51	1·57	·06	266
15	1·23	1·18	·05	430
15	·55	·6	·05	642
30	2·71	2.73	·02	262
30	1·83	1·8	·03	424
30	·9	1·00	·10	562
45	2·47	2·49	·02	270
...	1·79	1·82	·03	371
...	·67	·75	·08	546

Vessel, 165ft. × 25ft. × 9ft. 5in. Model made to a scale ½ in. = 1 foot.
Fine light-draught steamer. Weight of Model, 7·5 ounces.

S.S. *C*———.

RIGHTING LEVERS.

Angle.	By Machine.	By Calculation.	Difference.	Displacement.
	Feet.	Feet.	Feet.	Tons.
15	1·26	1·14	·12	1,537
15	·76	·79	·03	3,500
30	2·08	2·12	·04	1,660
30	1·4	1·48	·08	3,607
45	2·85	2·87	·02	1,860
45	1·71	1·66	·05	3,810
60	3·03	3·02	·01	1,865
60	1·78	1·74	·04	3,604
90	1·13	1·21	·08	1,553
90	·81	·73	·08	3,450

Vessel 257ft. × 35·1ft. × 20·1ft.
Model made to a scale $\frac{1}{4}$ in. = 1 foot.
Type, raised quarter-deck, combined with bridge-house.
Weight of Model, 8·7 ounces.

APPENDIX.

DESCRIPTION OF BALANCE EMPLOYED IN EXPERIMENT. FIG. 1, PLATE XLI.

A—Steel straight-edge.

B and C—Steel tee-squares fastened to straight-edge by a small bolt.

E E—Knife-edge bars at ends of straight-edge from which the scale-pans F and H are suspended.

K—Knife-edge bar on which the straight-edge oscillates. The knife-edges work upon two steel hardened plates, which rest upon supports fastened to the tank.

A small sensitive spirit-level having a ground glass is fixed to the straight-edge in order to ascertain when it is balanced.

The top of the straight-edge is marked so that the distance between the fulcrum and the scale-pans is divided into 10 divisions, and each of the latter again into 10 parts. This dispenses with the use

of very small weights, as for example: 1oz. placed at the No. 4 mark would represent ·4oz. placed in the scale-pan.

Again, if ·1oz. were placed at the 2·1, 3·7, or 5·2 mark it would correspond respectively to ·021oz., ·037oz., and ·052oz. placed into the scale-pan.

Directions for Making Models.

Procure some sheets of oil-paper such as is used in a letter-copying press, and with spirit-varnish join four sheets together. Having a number of such, cut them up into convenient sizes.

After this, mark on each piece a vertical line X X and two horizontal lines Y Y three inches apart, Fig. 2, Plate XLII.; at their intersection cut out with a chisel $\frac{5}{16}$ in. square holes, so that the sheets will slip over the pins P P, Fig. 2.

Suppose a model is required of the vessel whose longitudinal plan is shown in Fig. 3, Plate XLII.

1st. Divide the length into about twelve equal intervals, and then from the body-plan make a tracing of the form of the vessel at the centre of each interval.

Mark on the tracing the assumed position of the centre of gravity of the vessel, and draw a horizontal line through it.

Lay the tracing of the body-plan upon each section so that the centre lines coincide and prick off the form of the vessel at that place, after which cut the sections with a pair of scissors closely to the marks.

Take the first section and lay it over the square pins on the plate A, Fig. 2; varnish it with spirit-varnish and then put on the second section, and so on until the whole of the sections are together.

The square pins P P on the plate A will keep all the sections fair to each other. Before removing the model lay a straightedge on each side of the pins P P and N N and draw the lines *a a* and *b b*; exactly between these lines will be the mean centre lines of all the sections; by working to these centre lines any error due to the holes not being cut quite fair, or to the sections being slightly out of place, will be practically neutralised.

When the model is removed from the plate it should again be varnished, and when dry put into a copying press and slightly pressed, somewhat similar to the plan usually adopted with ordinary paper models. The various angles for which righting-arms are required should be marked on the model.

Various lengths of erections can be taken into account by using paper of two or three thicknesses. The ordinary sections should, however, as already stated, be made of four thicknesses unless thick oil-paper can be procured.

The model is fastened to the tee-square B and fixed at any angle by a small bolt, which is shown full size in Fig. 1; a small bolt must also be put into the tee-square C, so that only the sections when immersed in the water affect the equilibrium of the balance.

If prepared paper, with the square holes cut out, is kept in stock, models can be quickly made.

Further experiments seem to indicate that with a slightly modified form of balance, the paper sections need not be joined together, if this does not entail any loss of accuracy. Old models could be utilised for models of smaller vessels.

Note.—This has not fully been tried.

STABILITY CALCULATIONS BY MEANS OF THE PLANIMETER.

By Ludwig Benjamin, Esq., Member.

[Read at the Twenty-eighth Session of the Institution of Naval Architects, April 1st, 1887; the Right Hon. the Earl of Ravensworth, President, in the Chair.]

Nearly all the methods which have been published for the calculations of cross curves for the stability of ships, are based upon the application of the integrator, and although this is a very useful instrument, there are evidently many calculators who will be glad to learn of a method for which the planimeter is available; for, unless you have a staff of well-trained boys or girls for the operation, the latter becomes very tedious and laborious, because, as the process by which the instrument arrives at its results, is masked during the operation, it is not very easy to detect such fundamental errors to which the work with such instruments is always liable.

For the method which I published in this Institution in 1884, either Simpson's Rules or the integrator are applicable, but most of those who have made use of the system have employed the former means.* It will be, however, evident that for accurate and reliable results Simpson's Rules are not all that can be desired.

On the other hand, the planimeter combines, with the accuracy of the integrator, the advantages of being simpler, cheaper, and that you always know what you are doing. For these reasons I have modified my method in such a manner as to suit the application of this instrument.

It will be remembered that the problem before us is to find, for any given angle of inclination of a vessel, the position of the resultant of the upward water pressure P, Fig. 1 (Plate XLIII.), for a number of load water-lines. We have therefore to fix an axis, X X, vertical to the water-lines, the position of which is arbitrary, and to find the moments of the respective immersed bodies, W K E L, about this axis, which moments, divided by the corresponding volumes of the bodies W K E L, give the distances of P from X X.

* The specimen calculation-sheets which I worked out for that purpose were not published with that paper, but are to be found in Sir Edward Reed's book, "The Stability of Ships."

Our material being the transverse sections of the body plan, we have to find the areas and moments of these sections, and to compute from these the totals.

To make the planimeter applicable for these operations we have to construct a new set of curves, the *areas* of which are equal to the *moments* of the sections in the body plan, and it is the construction of these curves which forms the novel part of this paper.

The figures on Plate XLIV. illustrate these curves. Although on the first glance they appear to be complicated, it will be seen, on closer examination, that such is not the case, and that to construct them from the body plan does not entail much more work than to make a copy of the latter. Their construction is based upon the following principle :—Corresponding with the (inclined) equidistant water-lines in the body plan, Fig. 2 (Plate XLIII.), a number of radial lines, Fig. 3, are drawn at equal angular intervals through a point O. These radial lines are marked by figures corresponding with the water-lines in the body plan. The circle Z Z in Fig. 3 is drawn with such a radius that, if the angular intervals are measured on its circumference, they are equal to the intervals of the water-lines in the body plan. The point O corresponds with the axis X X, about which the moments are to be taken. By means of a strip of paper, the distances from X X of the intersections on each water-line in Fig. 2 are transferred to Fig. 3 as distances from O, so that, for instance—

R A in Fig. 2 = O A^1 in Fig. 3.
R B „ „ = O B^1 „ „ &c.

The spots are connected by curves corresponding with the sections of the body plan.

The areas of the new curves have the quality of being proportionate to the moments of the original figures about the axis X X. To get the actual value of these moments the areas have to be multiplied by the radius r of the circle Z Z. We have, for instance—

Area A^1 K^1 E^1 B^1 $\times$ r = moment of A K E B about X X.
„ C^1 K^1 E^1 D^1 $\times$ r = „ „ C K E D „ „ &c.

The mathematical reason for this will be found in the Appendix, where are also given some details which are valuable for the quick and correct construction of the moment curves.

On Plate XLIV. the body plans for the fore and after body of a vessel are given, and the moment curves for 20° and 90° inclination, which latter diagram serves also for the determination of the height of the centre of buoyancy in upright position. The principle and character of the moment curves is fully illustrated by these figures, as the operation for other angles of inclination is similar in all respects, to that for the angles selected for illustration.

Having constructed these moment curves, it remains to take by the planimeter the areas of the sections in the body plan up to the different water-lines, and the areas of

the moment curves up to the different radii which correspond with the water-lines in the body plan.* The results thus obtained represent the areas and moments of the transverse sections, and their integration in longitudinal direction does not offer any novel features.

In the papers which treat the application of the integrator to stability calculations, viz., those of Mr. Denny and Dr. Amsler, in 1884, it is recommended to carry out this longitudinal integration by means of Simpson's Rules. The transverse sections are for that purpose placed at equal intervals, and the readings from the integrator are taken collectively for those sections which come under equal multipliers. The same treatment might be given to the readings from the planimeter in the method I have described, but it appears to me, that there are strong reasons against this mode of operation, whichever instrument is applied. They are the same reasons which I brought forward at the last spring meeting at the discussion of Mr. Heck's paper, and which I pointed out at greater length in a paper read before the Liverpool Engineering Society in 1885.

It appears to me preferable to construct longitudinal curves of areas and moments by plotting off the planimeter readings to a scale (as shown on Plate XLIV., for the values of 20° inclination). The areas of these curves are again to be computed by the planimeter, with the result of finding the displacements up to the different water-lines and their moments about the assumed axis. Besides increased accuracy, these longitudinal curves offer the advantage of forming a perfect check upon the readings from the planimeter, and if the sections are placed judiciously, fewer of them are required than if the readings from the planimeter (or integrator) are treated by Simpson's Rules.

The construction of the cross curves from these results does not require any comment.

I have given the method which I have described, many trials in actual calculations, and have found that it requires not much time, and that it is very lucid, and by its graphic nature totally free from sources of error. The moment diagrams for the different angles form a very interesting study, and show off the characteristics of the stability of different vessels in a very clear manner, and I have published the system in the hope that other designers may find it as useful as it has been to myself.

* In cases where the height of the centre of buoyancy (instead of the horizontal position of the resultant pressure) is to be investigated, the water-lines are represented in the moment diagram by circles instead of radii.

APPENDIX.

In Fig. 4 (Plate XLIII.) a curved figure W K L is given, and let X X and Y Y be the axes of co-ordinates. For a given x we have two ordinates, y_1 and y_2. The area of figure W K L is—

$$A = \int (y_2 - y_1)\, d\,x,$$

and the moment of W K L about X X is—

$$M = \tfrac{1}{2} \int (y_2^2 - y_1^2)\, d\,x$$

Now let Fig. 5 (Plate XLIII.) be constructed in such a manner that the abcissæ of Fig. 4 are set off on the circumference of circle Z Z, starting from that point which lies on radius O T, which is made to correspond with Y Y (or W L) in Fig. 4. The ordinates y_2 and y_1 for each value of x are set off from the centre O of the circle Z Z, on those radii which pass through the corresponding points of Z Z. Let r be the radius of Z Z.

Considering a parallel strip of the breadth $d\,x$ with the abcissa x, in Fig. 4, it is represented in Fig. 5 by a triangular strip which measures $d\,x$ on circle Z Z. The breadths of this strip at the radii vectores y_2 and y_1, are respectively—

$$d\,x\,.\,\frac{y_1}{r} \text{ and } d\,x\,.\,\frac{y_2}{r}$$

The part of the figure W′ K′ L′ which falls within this triangular strip, and which corresponds with the strip $(y_2 - y_1)\, d\,x$ in Fig. 4, is therefore—

$$\frac{d\,x\,.\,y_2}{r}\,.\,\frac{y_2}{2} - \frac{d\,x\,.\,y_1}{r}\,.\,\frac{y_1}{2}$$
$$= \frac{1}{2\,r}\,(y_2^2 - y_1^2)\, d\,x.$$

and the total area of the figure is—

$$\frac{1}{2\,r} \int (y_2^2 - y_1^2)\, d\,x = \frac{M}{r}$$

The area of Fig. 5 is therefore equal to $\frac{1}{r}$ of the moment of the original figure, taken about X X, and as Fig. 4 corresponds with the body plan, and Fig. 5 with the moment diagram, the principle of the method is thus proved.

It will at once be evident that all straight lines which are in the body plan parallel to the axis X X (or vertical to the inclined water-lines) must be circles in the moment diagram, their distance from O being constant. All straight lines which are parallel to the inclined water-lines (or vertical to X X) will be radii in the moment diagram, and all other straight lines in the body plan will develop into Spirals in the moment diagram, their distance from O increasing in proportion with the angle of the radius vector. As an example of the latter, see the middle lines in the moment diagram for 20° inclination, on Plate XLIV.

For the construction of the moment diagrams it is often necessary to find the position of points which do not lie on the given equidistant water-lines in the body plan. For that purpose it is necessary to construct auxiliary water-lines. To find, for instance, the position of the gunwale point M, section 6 in the fore body, Plate XLIV., draw the inclined water-line through M in the body plan, which has the distance t from water-line V. Set off this distance from radius V on circle Z Z, and draw the new radius, which corresponds with the auxiliary water-line through M. The point M′ in the moment diagram is now found by measuring from O on this radius the distance which M has from X X.

It is furthermore of great assistance sometimes, to construct tangents in the moment diagram, corresponding with tangents to the sections of the body plan, parallel or vertical to the inclined water-lines. As has been explained above, these will appear in the moment diagram as radii or circles respectively.

Thus the tangent parallel to X X in N, section 11, in the afterbody, is represented in the moment diagram by a circle of the radius s, which is equal to the distance of N from X X, and the position of N′ is found by means of the radius which corresponds with the auxiliary water-line drawn through N, as explained above.

By means of these tangents and the construction of marked points, the drawing of the moment curves becomes a matter of little difficulty, and it can be done in a very short time.

The angular interval of the radii is a matter of convenience. It appears preferable to choose some angle which is easily constructed, and then find the radius r of the circle Z Z by calculation. Let the angular interval be $\frac{\pi}{n}$, and the interval of the corresponding water-lines in the body plan, d, then

$$d = \frac{\pi r}{n} \quad \text{or} \quad r = \frac{d\,n}{\pi}$$

In Plate XLIV., where the angular interval is $10^\circ = \frac{\pi}{18}$, and $d = 4$ ft., we have thus

$$r = \frac{4 \times 18}{\pi} = 22{\cdot}93 \text{ ft.}$$

The areas of the moment diagram multiplied by 22·93 ft. give, therefore, in this instance, the moments of the sections of the body plan.

In setting off the ordinates for the longitudinal curves, it is, however, sufficient to take the actual planimeter readings, and multiply the final results by r, as it has been carried out on Plate XLIV.

DISCUSSION.

Mr. F. P. Purvis (Member): My Lord, I was in hopes someone else would rise first, but as I have a few remarks to make on both these papers, perhaps I had better make them. With regard to Mr. Benjamin's paper, I think we must all be very highly pleased with this new application, shall I call it, of a very old instrument, the Planimeter, and with the way in which, with Mr. Benjamin's help, and by the use of the Planimeter, we can do, if needs be, without the more complicated improvement

upon the Planimeter, the Integrator. Mr. Benjamin points out, and it is just as well that we should remember it, that the labour in adopting his method, apart from the question of forming his curves, is just double the labour required with the Integrator, so that, although the results obtained are very beautiful, it behoves anyone in putting to himself the question, Shall I be content with the Planimeter, or shall I get an Integrator? to consider whether the saving of more than half the time is worth the cost of the Integrator. One point of Mr. Benjamin's paper I entirely disagree with. On page 445 he says that, instead of using Simpson's multipliers for the integration longitudinally, he prefers to set off a curve graphically, and to integrate that curve again by the use of the Planimeter. For a ship in which he is perhaps dealing with five water lines for say half a dozen angles, he would have to set off 30 (5×6) curves in that way. I certainly feel that the extra time that takes is not worth the gain resulting. That is not all. There is a still further loss of time in setting the readings off graphically. In Dr. Amsler's method, to which Mr. Benjamin refers, the work was so arranged that readings did not require to be made of every section, but several of the sections were combined together, and a result obtained after all these sections had been gone round; perhaps four sections would be so taken together, one reading before and one reading after being sufficient; whereas, if Mr. Benjamin's plan were adopted, each section would have to be taken independently and separately, and the work would thereby be very considerably increased. At this point there comes a connection between Mr. Benjamin's paper and Mr. Heck's paper. Mr. Heck in all the work that he has done—I won't say all the work, because I know he has had in his mind something else, but in most of the work he has done, and in all the work he has brought before this Institution—has worked with what we know as the trapezoidal rule. If Mr. Heck by the trapezoidal rule gets such excellent results, then it cannot surely be necessary for Mr. Benjamin to insist that even Simpson's rule is not sufficiently accurate for this longitudinal integration. But that is a matter I should like someone to take up, and to say what is the end involved in Mr. Heck's method by taking the trapezoidal rule, which we know is, to say the least of it, imperfect. With regard to Mr. Heck's machine, I think we must all be immensely pleased with the beauty and with the extreme simplicity of it. I am rather afraid he has gone too much on the small size. His results seem to disprove that, but one has rather a feeling I think that perhaps he has gone to too small a size; still to look at it and to judge from the results as he has brought them before us, I think we cannot too much admire it.

Mr. W. John (Member of Council): My Lord, I may mention, with reference to the point raised by Mr. Purvis, that the relative accuracies of Simpson's rule and the trapezoidal rule will be found set out very fully in some of the earlier numbers of our own Transactions. Mr. Merrifield read several papers in this Institution on the subject. I am not going to detain the meeting by discussing the papers, they are both interesting, and interesting from different points of view, and I think they will add value to the Transactions and will be useful to any younger students of naval architecture coming up. I wish to thank the writers for their papers.

Mr. Purvis: My Lord, will you allow me one word of explanation?

The President: It must be in explanation only.

Mr. Purvis: It is in relation to what Mr. John has just said. It is not simply a question of the accuracy of Simpson's rule or the trapezoidal rule in itself, but it is a question to what extent two inaccuracies destroy one another. You are applying Simpson's rule and the trapezoidal rule to get moments, and you are applying Simpson's rule and the trapezoidal rule to get displacement, and then you are dividing moments by displacement, and although by the one rule the moment obtained may be

too much or too little the displacement will also be too much or too little, and the result of the division may be very nearly what is right.

Mr. J. H. Heck (Member): My Lord, I am surprised that the relative accuracy obtained by the trapezoidal as compared with Simpson's multipliers, has come up again, as practically there is no difference in the values of the righting arms obtained by the use of either. Mr. Benjamin raised the question last year, and I think I mentioned that when at Dumbarton, at Mr. Denny's establishment, this question was discussed between Dr. Amsler and myself, that gentleman, I believe, made some calculations which confirmed mine, that while there might be some little difference in the displacement, there was practically none in the righting levers. Had the employment of the trapezoidal rule in the longitudinal direction not been fairly accurate, we should not have got such nearness in the results as those given by the experiments detailed in my paper of last year and the previous year. I may also mention that in France the trapezoidal rule is almost universally used by naval architects, and that there are also firms in this country who employ it in their drawing office for practical work. I have nothing more to add, except to thank you for the attention with which my paper has been listened to.

Mr. L. Benjamin (Member): My Lord, I have only a few remarks to reply to. First of all I must admit that the method I have brought forward requires a little more time than that by the Integrator. But it would be driving things too far if we were to look at time only in this class of work. If I myself had a chance to work either by the Integrator or by the Planimeter, I should certainly prefer the latter instrument, in spite of the slightly increased time required. It is because I can rely better on the results. You cannot rely quite as much on the Integrator. The saving of time by the latter comes in principally by taking collectively the sections with equal multipliers. Now, assume that in going over one such set of sections, you make two errors, one positive and one negative error. Let one of them amount to 9 per cent. of the total reading of that set, the other to 7 per cent.; well, there is a total error of 2 per cent. made in the reading of that set, which you may not be able to detect at a second reading, because you may have mistaken some lines, and make the same mistakes at the second operation. Still, the error is too small to make the result *appear* wrong. That is quite a common occurrence with the Integrator, but it is quite impossible with the Planimeter. That is one of the reasons why I am so much in favour of the latter. In regard to the value of the trapezoidal rule, it may be that for many vessels there will be little difference between the accuracy of this and Simpson's rules, though the latter is always more reliable. Both, however, are inferior to integration of the continuous curve by mechanical means. In reply to what Mr. Purvis said in regard to conformity of the results of Mr. Heck's experiments and the calculations, I do not admit that that proves that either Simpson's or the trapezoidal rule are accurate enough for the longitudinal integration, because, as I pointed out last year, if there is an error in one of them, it must be in the other also, the same rules being applied to both. That is all I have to say; and I conclude by thanking you for the kind reception my paper has met with.

The President: Gentlemen, I will now on your behalf convey to Mr. Heck and to Mr. Benjamin our thanks for these two papers; and if the discussion has not assumed quite the proportions and the length that they possibly might have expected, I think probably it may be due to this circumstance, that the calculation of stability curves, and of the questions connected with that subject have received for the last two or three sessions to my own knowledge, such very ample and exhaustive discussion, that that possibly may have been the reason, and not any want of respect to the authors of these

papers. The subject has been pretty well thrashed out, as we all know, during the last two or three years. I think, probably, that may be accepted as a reason why the discussion has not been of that length that perhaps the authors of the papers might have expected. I beg to thank those gentlemen. We all know that the labours of Mr. Heck have resulted in a most ingenious appliance which he has invented for this purpose; and we have to thank Mr. Benjamin for the great knowledge which he always displays in discussing this question of stability.

CONCLUDING SPEECHES.

Admiral Sir John Hay (Vice-President): Lord Ravensworth and Gentlemen, I have been requested by my colleagues to make a motion which I am sure will not be considered a formal motion, but one which you would naturally expect and desire. At the conclusion of these interesting meetings, it is but due to our President that we should offer him a vote of thanks for his urbanity, his kindness, and his fairness in the chair. It is due to Lord Ravensworth to say that no chairman has ever presided over meetings with greater satisfaction to those who form the meetings, and that we always feel confidence (both in the Council and here) when we see him presiding over our deliberations. It will be our good fortune to hold our next meeting at Newcastle-on-Tyne, by the kind invitation of those who reside there; and in Sunderland, where also our President is well known and highly esteemed. He is the near neighbour of Newcastle-on-Tyne, and we shall there see not only his ability and his admirable performance of his duty as we see it here in this Metropolis, where there are many others who perform great duties equally well, but we shall see him near his own home, where, as a country gentleman, as an old member of the House of Commons, and as a peer who attends with the greatest possible interest to all public business belonging to the counties both of Durham and Northumberland, you will see how he is respected. We are looking forward to that occasion with great satisfaction; and now, my Lord, it is my duty to ask the meeting to give you a vote of thanks for your conduct as President on this occasion.

Mr. B. Martell (Vice-President): Gentlemen, I am desired to second this vote of thanks which has been proposed by Sir John Hay. I think that he has expressed himself in such excellent and beautiful terms that it would be unnecessary for me to say more, were it not that I feel it an honour to be called upon to second this—not only a duty but an honour—as on all occasions when I have had either to propose or to second a vote of thanks to our noble President for the manner in which he presides over our meetings. It is not only here that we have seen the able manner in which he conducts the functions devolving upon him of presiding over our meetings; but when we call to mind the able and more than ordinarily satisfactory way in which those duties were performed by Lord Ravensworth when we were at Liverpool, I am sure we must all feel proud of our President. Like Sir John Hay, I am sure that when we go to Newcastle, as I hope we shall, we shall there see a repetition of that capable and able manner which we all so much admire; and I can anticipate the pride which we shall feel in being presided over by a nobleman possessed of so much special knowledge rendering him so capable of presiding over our meetings, and of representing this Institution. I have very great pleasure in seconding this proposition, and I feel sure you will agree with me when I say that every year that our meetings are presided over by our present President, we feel more and more the honour we did ourselves when we solicited his lordship to accept the position which he now occupies.

Sir John Hay put the resolution, which was unanimously adopted.

The President: Gentlemen, if I had been a shy man, I should have been under the table a long time ago, because the expressions made use of by the proposer and seconder of this resolution have been so much too flattering that they really have taken my breath away; but I am very grateful indeed to my friend Sir John Hay, and to my old friend Mr. Martell, for the much too flattering terms in which they have conveyed to you their wish that you should pass this vote of thanks. I thank you all with all my heart for this kindly expression of your feeling. You do not of course know my own feelings quite so well as I do, but I can assure you that every year that I sit here I feel more and

more strongly how very inefficiently I am able to perform the duties of this chair. (No, no.) Well, I feel it to be so; and I am very glad to express it, because it will, I hope, serve as a caution to you to excuse the many shortcomings of the chair, and the many failures that I necessarily make, not being a scientific man, in taking that part in your discussions which you have a right to expect from your President. The conduct of our meetings is so admirable, and the tact and the temper that is shown—I am speaking now in sober earnestness—in the course of these discussions, which naturally tend to create a certain amount of heat in people who take a keen interest in their subject, that it makes my duty practically a sinecure, and I have never had the slightest difficulty whatever in presiding and exercising the duties of the chair, owing to the tact and temper which are always exhibited on your part. Now, gentlemen, I want to say two or three words only before I sit down. There was an idea at one time that our session this year would be somewhat lacking in interest. Now, it is always a much wiser thing to judge by results than to attempt to prophesy, and I think you will all bear me out when I say that our discussions this year have equalled in interest, and almost excelled in ability, the discussions which have taken place upon the papers at almost any previous meetings. Subjects have been discussed, and questions have been dealt with, which are of immense public interest at this moment. I will only just allude to the question, for instance, of the coal capacity of our fast cruisers of the Royal Navy. That subject has been discussed with great ability. You have heard the opinions of the men who navigate the ships, as distinguished from the views of those who have designed those ships, and you have been able to form your own conclusions. You have had the whole question of side *versus* internal armour discussed with immense ability and admirable temper, I may say. You have had this very evening a discussion upon twin screws, which is second to none in importance, I imagine, to the Mercantile Navy at this moment. There is great economy in the long run in the use of these steamers, and now that the great tendency of our shipowners, and our shipbuilders, too, is to increase largely the size of our merchant ships, I hope the time has come when those mighty and costly ships, with their valuable cargoes, will no longer be trusted to single screws; and therefore the discussion upon twin screws, such as we have had this evening, must, in the eyes of the mercantile world, be of very great value indeed. Well, now, gentlemen, I have to congratulate you. I have to congratulate you with all my heart upon the result of our meetings this year. I think they have been admirably adapted to the questions that are uppermost in the public mind at this moment. I have only alluded to two or three of them, not in disparagement of other papers at all, but I have merely picked them out as questions which are really before the public mind out of doors very much at this moment. I now wish to congratulate you upon a matter of very great interest to us all, and that is the increase in our Members. I do not know whether you are aware that we increased our Members by 150 last year, and no fewer than 75 new Members out of that number were enrolled at our meetings at Liverpool. I trust you are all going to visit my own native county this year, the North-East Coast of England. I ought to mention, before I leave that subject, that we have just enrolled 47 new Members and Associates, and I look with considerable hope to a still further considerable increase of our numbers at our summer meeting in Newcastle. Speaking on behalf of the North of England, I can promise you one thing most confidently, and that is a hearty welcome. And I think I can promise you also many objects of interest. Many of you are not perhaps acquainted as well as I am with the North of England; I think we shall be able to show you many things worthy of your notice. First, I would mention our great northern arsenal at Elswick. I think a visit to that place will amply repay anybody who takes the trouble to go to the North to see it. We shall be able to show you the latest works for the improvement of the navigation of the Tyne—one of our most important ports, whether regarded as a port of import or of export. We shall, I hope, be able to show you some private

establishments which will be worthy of your notice, and I shall appear there perhaps in a double capacity. I shall hope to show you an exhibition of which I have the honour to be President, and which I believe and hope will be worthy of the industrious neighbourhood which you are about to visit. Gentlemen, I beg to return to Sir John Hay, to Mr. Martell, and to one and all of you, my unfeigned thanks for the kind way in which you have expressed your sense of the very humble and imperfect duties which I am able to perform in this chair. I hope we shall all meet another year in good health, and in greater prosperity than we have enjoyed for some time.

Admiral A. F. R. De Horsey (Associate): I have been commissioned, my Lord and Gentlemen, to ask your vote of thanks to the Council for the hard work they have done, and the excellent way in which they have performed it. Gentlemen, we are much indebted to the Council for the trouble they take in the selection of papers, and in managing our affairs, and in increasing our numbers. As you are aware, the whole of the work of the Institution is done by the Council, and I think that we shall, one and all, be glad to tender them our thanks. The Council have also, from time to time, rendered much public service. In 1864 they were the cause of the School of Naval Architects being introduced, and if you only think of that one service, that alone will show how useful to the nation the Council of this Institution has been. Of what their services have consisted during the past year, I am naturally unable to speak; but I feel sure that the Council have rendered good service to the Institution, and I ask you to give them your vote of thanks.

Mr. S. W. Barnaby (Member): My Lord, it is my privilege to rise to second this vote of thanks. I do not know personally what the duties of the Council are, whether they are arduous or not; I had forgotten to ask the Secretary. But of this I am quite sure, that, judging from the results, whatever they were, they have been exceedingly well carried out, and that the thanks of the meeting are due to them in a very special degree. I beg to second that vote of thanks.

Admiral De Horsey then put the vote to the meeting, and it was carried unanimously.

Mr. MacFarlane Gray (Associate Member of Council): My Lord, I have been requested to return thanks for the Council. Why I have been asked must, I suppose, be somewhat upon the same principle that the youngest bachelor is always asked to reply to the toast of "The Ladies," he having least experience of them. Although of the Council, I have done so little of its work that it would really better become me now to join with you in your expressions of appreciation. I can testify to the harmonious, faithful working of my fellow Members, and I can assure you that the hearty approval conveyed in your vote of thanks is much esteemed by the Council of this Institution.

Sir Nathaniel Barnaby (Vice-President): My Lord, may I take two minutes to point out another duty which we have to perform. I am sure that all of us who have been here at these meetings have been pleased, as our President has been kind enough to say, with the temper with which the meetings have been carried out, and with the important discussions which we have had. I think we are all of us separating in good temper, my Lord. There was one thing that came to my mind this afternoon, when I left the room, and that was, lest there should be a little want of courtesy towards our friends from France, whom we have been so delighted to see here. I have been, my Lord, pleased to find that that is removed, and that our hearty thanks may be given to our friends, Mons. L. De Bussy and Mons. E. Widmann, for the communications they have been good enough to make to us. What I rise for is to propose, as we do every year, and as it is our duty to do, our very

grateful thanks to the Council of the Society of Arts, for giving us the use of this splendid room. This is the twenty-eighth time that they have done that for us, and we know well how much the progress and success of this Institution has been due to that piece of generosity on their part. I propose that a vote of thanks be given to them.

Mr. J. Inglis, jun. (Member of Council): My Lord, I have much pleasure in seconding the motion proposed by Sir Nathaniel Barnaby, that we pass a hearty vote of thanks to the Society of Arts for the use of these commodious rooms. In the part of the country I come from, trespass has only to be continued long enough to constitute a legal right, and the trespasser may defy the proprietor to put him off his territory. I do not know whether that is good law in London, but, whether it be so or not, I hope we shall never take advantage of it, nor forget that we are very much indebted to the Society of Arts; and that, so long as we enjoy the privilege, we shall never be slow to express our gratitude for it. I was much pleased to hear your Lordship read of the great accession we had had to our Membership; and, if in the future our Members increase as rapidly, we may hope, in a few years more, to have rooms of our own. But while we are indebted to the Society of Arts, let us not forget to return our thanks to them, annually.

The President: Gentlemen, I won't call for a show of hands. I will ask you, please, to carry this by acclamation. Now, gentlemen, before we part, I must ask you to allow me the privilege of proposing to you a vote of thanks to our Secretary. (Hear, hear.) Everybody knows, who is connected, and many of you are connected probably, with other learned institutions and societies, that the greater part of the work of all these institutions is, throughout the year, practically conducted by the Secretary. It is ill praising a man to his face; but I am bound to say, having had very intimate relations with our Secretary, now for several years, that I have ever found him up to his work, ready to do his work, and doing it with an amount of ability which does the Institution itself the highest possible credit. I won't say more than that I think the courtesy, the willingness, and the ability to work, which are shown by our Secretary, would make it extremely difficult to replace him adequately in the services which he is called upon to perform. Will you carry that by acclamation, likewise?

[Carried by acclamation.]

The Secretary (Mr. G. Holmes): My Lord and Gentlemen, I am extremely obliged to you for your great kindness to me, but the truth is, I meet with such cordial support from every Member of the Council, and not only from every Member of the Council, but from every Member of the Institution with whom I come into contact, that my work is reduced to a minimum, and is made an immense pleasure to me. I thank you most cordially.

MEMOIR OF MR. WILLIAM DENNY, F.R.S.E.

In the Spring of the present year the Institution sustained a severe loss through the death of Mr. William Denny, F.R.S.E., in South America. Mr. Denny was born at Dumbarton on May 25, 1847, and was educated partly at the Academy of that town and partly at Edinburgh High School, where, under Mr. John Carmichael, he was thoroughly grounded in the classics. His early education does not seem to have had any connection with his future profession, for it appears that he attained his knowledge of science and mathematics through hard and systematic study during and after the period of his apprenticeship. When, at the age of seventeen, he resolved to become a shipbuilder, he was apprenticed at his father's shipyard, and there underwent a thorough course of practical training, and acquired a knowledge of his work-people which afterwards proved of the greatest advantage both to him and to them. When he became of age he was admitted by his father as a partner in the firm of William Denny Bros., and in that capacity, till the end of his life, he was distinguished both for technical ability, for power of organisation in the yard, and for business aptitude in managing the affairs of one of the largest shipbuilding firms in the country.

It is necessarily with the scientific and technical side of his career that this memoir chiefly deals. When he was still very young, in fact, only just of age, he read his first paper on a professional subject in public. The subject was "The Dimensions of Sea-going Ships," and the lecture was delivered before the Literary and Philosophical Society of Dumbarton, in December of 1869. In the following year he delivered a course of four lectures on the subject of "Iron Shipbuilding," and in the same year he commenced the practice with which his name subsequently became identified, of trying steamers at progressive rates of speed on the measured mile, with the object of constructing for each vessel a speed and power curve. The advantages of carrying out such progressive trials have been so often discussed at this Institution, that it is unnecessary here to refer to them in greater detail. In 1871 he read his first paper on the subject, at Dumbarton.

It was in the year 1870 that Mr. Denny first became connected with the Institution of Naval Architects, and in the following year he first joined in our discussions. He has often told the tale, with evident amusement, of how difficult he found it on that occasion to obtain a hearing; how he was three times ordered to sit down, but how he persisted in speaking, and finally succeeded in making himself heard. If Mr. Denny's career were now about to open, instead of unfortunately having closed, he would doubtless not need to complain of a difficulty in obtaining a fair hearing. It was, perhaps, due to the difficulties which attended his first appearance that his remarks on that occasion were very short, and that he did not again intervene in debate till the

year 1876, when the late Mr. Froude read his well-known paper, "On the Ratio of effective to indicated Horse-power as elucidated by Mr. Denny's measured Mile Trials at varied Speeds." At any rate, when in the latter year he again appeared in our discussions, he was listened to with interest and respect, for in the meantime his name had become well known, and his reputation thoroughly established, by the good work which he had been doing in the North. In the previous year he had himself read two papers on the subject of "Progressive Trials," one before the Institution of Engineers and Shipbuilders of Scotland, and the other before the Bristol Meeting of the British Association.

His first paper communicated to this Institution was on "Lloyd's Numerals," delivered at the Glasgow Meeting in 1877, followed at the Spring Meeting in London, in the next year, by one on "Lightened Scantlings." In these he proposed to fix the scantlings of vessels on a basis of displacement, instead of on the numerals of Lloyd's Register.

Mr. Denny's firm were amongst the earliest to recognise and to take advantage of the qualities of mild steel for shipbuilding purposes. In the year 1876 they built their first steamer of Bessemer steel, viz., the *Taeping*, a light-draught paddle boat, constructed for the Irrawaddy Flotilla Company. Two years afterwards they built another steamer for the same Company, this time of Siemens steel, and in the year following they constructed the *Rotomahana*, for the Union Steamship Company of New Zealand, which was the first ocean-going merchant steamer built of mild steel. In 1880, Mr. William Denny, who was always ready to communicate to the profession, through the instrumentality of this and kindred institutions, the results of his professional experience, embodied the knowledge which his firm had gained in a paper on the subject of "Steel in the Shipbuilding Yard," which was followed up in the next year by a communication to the Iron and Steel Institute on the economical advantages of steel.

Mr. Denny delivered the Watt Lecture before the Philosophical Society of Greenock in the year 1882, the subject being "The Speed and Carrying Power of Screw Steamers," and at the meetings of this Institution in the same year he read two papers, one being on the subject of Launching Velocities, and gave the result of observations on the speed with which vessels built by his firm pass down the ways when launched. The second was on the "Reduction of Transverse and Longitudinal Metacentric Curves to Ratio Curves."

In the year 1883 the attention of naval architects was concentrated on the subject of the stability of ships. The natural result was a large number of papers on the calculation of stability in the Transactions of this Institution for the year 1884. One of the most important of these was contributed by Mr. William Denny, under the title of "Cross Curves of Stability, their Uses, and a Method of Constructing them,

obviating the Necessity for the usual Correction for the Differences of the Wedges of Immersion and Emersion." Shortly after the *Daphne* inquiry, it occurred to Mr. Denny that, as stability curves were required for at least four draughts of each steamer, it would be well if some method of obtaining these curves could be found which would facilitate their construction. The actual methods adopted were devised by two gentlemen on the staff of the firm, and are described in the paper. This was the last contribution of Mr. Denny to the Transactions of the Institution.

Mr. Denny's influence on the progress of naval architecture was by no means limited to the papers read before this and other scientific institutions. He was remarkable, as a business man and a shipbuilder, for his faith in scientific methods, and for his eagerness in endeavouring to apply the teachings of science to everyday commercial practice. His views on this subject cannot be better explained than by quoting his remarks in the discussion on two papers read by members of his staff, published in Vol. xxvi. of the Transactions: "What I claim, however, is that my firm have laid it down as a fixed policy that no theory shall be put forward in their office which is not immediately linked to practice. Such a policy is of value, because theory is continually rendered more fruitful by embracing practice, and practice is kept from degenerating into mere rule of thumb by being wedded to theory. I believe in such matters we are wiser and more sensible in the present day than we were in the past."* It was in strict accordance with these views that he determined that his firm should have an experimental tank for the purpose of trying model experiments, similar to that first set up at Torquay by the late Mr. W. Froude for the Admiralty. Another instance in point is the system of supplying owners and captains of merchant steamers with technical information concerning their vessels, and its bearing on their working and loading, which was devised by Mr. Denny and ably described by his brother in a paper contained in this volume of the Transactions. After the reading of Mr. Martell's paper on "Water Ballast" in Glasgow, in 1877, Mr. Denny was one of the first to appreciate the advantages of the application of the cellular bottom to merchant steamers, and in the year 1878 he applied and improved the system in the case of the steamships *Chilka* and *Chupra*, built by his firm for the British India Steam Navigation Company, and nearly the whole of the subsequent ocean-going steamers built by his firm have been constructed on this principle.

Mr. Denny was by no means exclusively known as a scientific shipbuilder. His was a many-sided nature, and he interested himself deeply in many subjects. Whatever he took up he carried through with characteristic energy and enthusiasm. He was distinguished for the active interest which he took in the welfare of his workpeople, an interest which he first acquired when working among them as an apprentice. He had a great belief in the value of conferences between employers and employed for the

* Transactions I.N.A., Vol. xxvi. p. 109.

settlement of all disputes and the regulation of wages. In 1884 he held a conference with his workmen for the purpose of revising the mode of collecting and dividing the subscriptions made by them to the various institutions and charities which they supported. There were present two delegates from each department in the yard, and the meetings were found to be productive of such good results that they were renewed during the two following years, and terminated in a complete revision of the yard rules. One of the results of the active sympathy existing between master and men was, that the Leven yard was one of the very few shipbuilding establishments on the Clyde in which the Trade Union of Iron Shipbuilders did not seek to interfere during the busy times of 1883. He established in 1880 a system of prizes and rewards, in order to encourage his men in effecting improvements and inventions in machinery and processes.

Mr. Denny was a strong advocate of improved technical education. In 1881 he read a paper before this Institution on the subject of "Technical Education in Naval Architecture," which resulted in a deputation of the Council waiting upon the Lord President to recommend an alteration in the Science and Art Department's examinations in naval architecture. A report of what took place when the deputation was received is to be found in Vol. xxii. p. 312 of the Transactions, and the practical outcome of the movement is contained in a letter from Mr. G. F. Duncombe to the Secretary of the Institution, which is published in Vol. xxiii. p. xix.

In the autumn of 1882 Mr. Denny's health began to suffer through the prolonged strain caused by his work, which was at that time extremely heavy on account of the large extensions which were being carried out in the yard at a time of exceptional business pressure. To restore his health, he took a prolonged holiday on the Continent. When returning home he and Mrs. Denny were unfortunately attacked by typhoid fever. The illness proved exceptionally severe, and though he recovered from it, he never quite regained his former health. In the summer of last year he left for South America, partly in connection with the business of the Plateuse Flotilla Company, of which he was a director, but chiefly to restore his health. The business part of the journey proved more arduous than he expected, and it is to be feared that his opportunities for regaining health were proportionately diminished. His constitution suffered instead of deriving benefit, and his life terminated on the 17th of March this year.

Mr. Denny will be nowhere more missed than in this Institution, where his genial nature and the great interest he took in all that concerned the welfare of the Society and his profession, made him deservedly popular. He was a frequent speaker in our discussions, and was always listened to with pleasure and interest. He was elected a Member of the Council in 1878. He was also a member of the Institutions of Civil and Mechanical Engineers and of the Iron and Steel Institute. At the time of his decease he was President of the Scottish Institution of Engineers and Shipbuilders, and he also enjoyed the distinction of being a Fellow of the Royal Society of Edinburgh.

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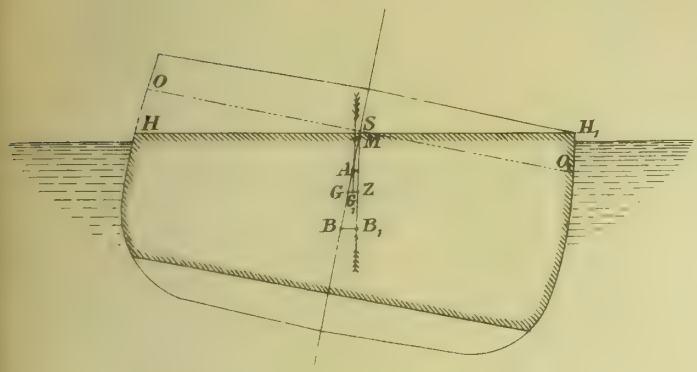
Fig. 1.



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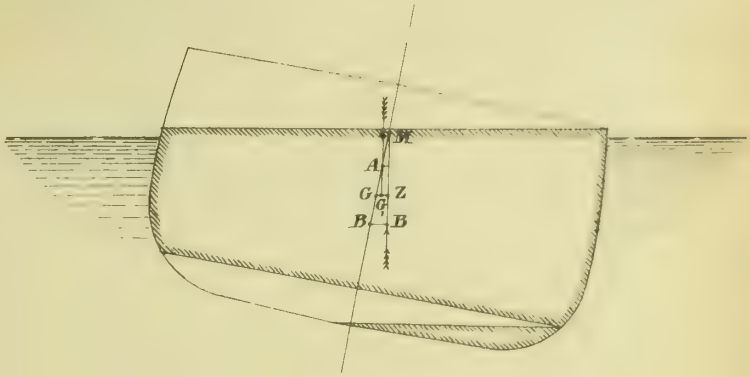

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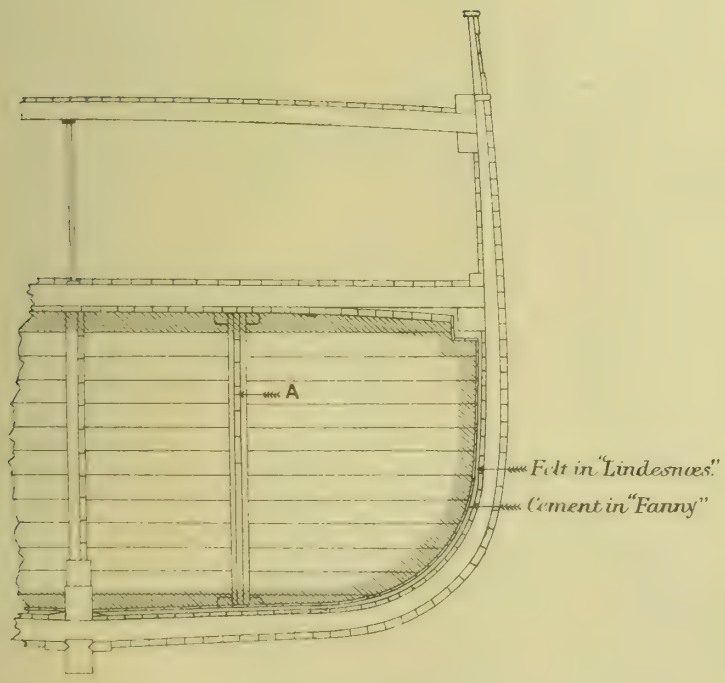
Fig. 3.



S. S. "VADERLAND."

Fig. 4.

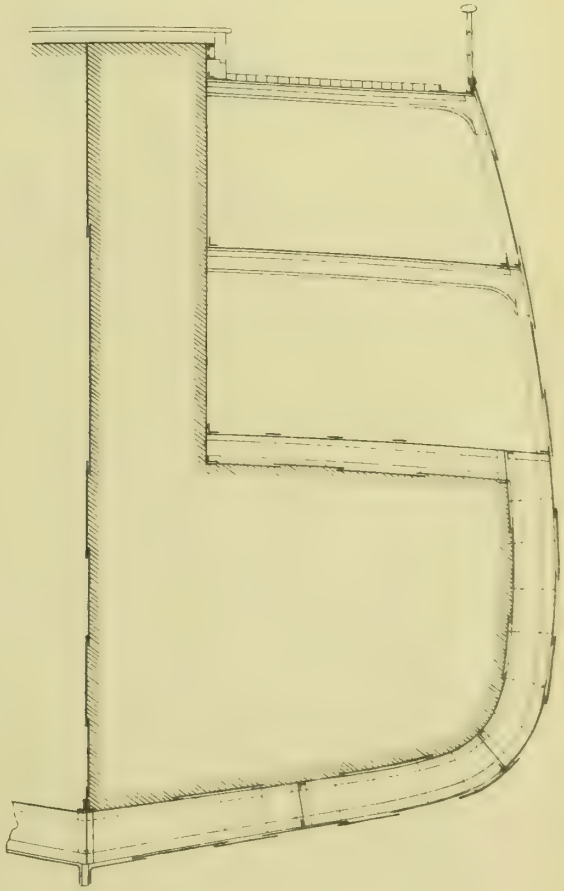


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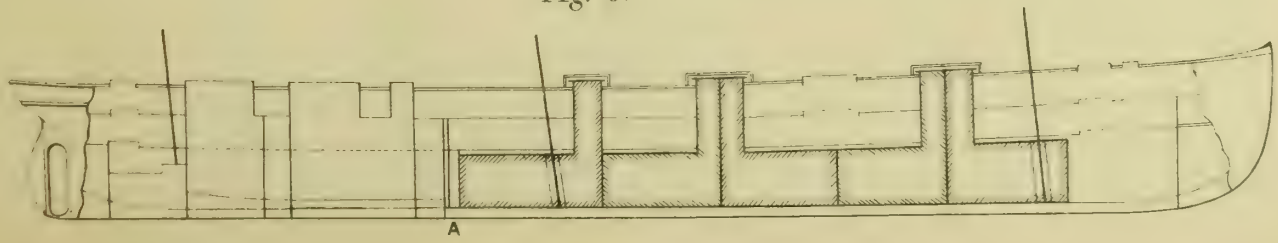
Fig. 5.



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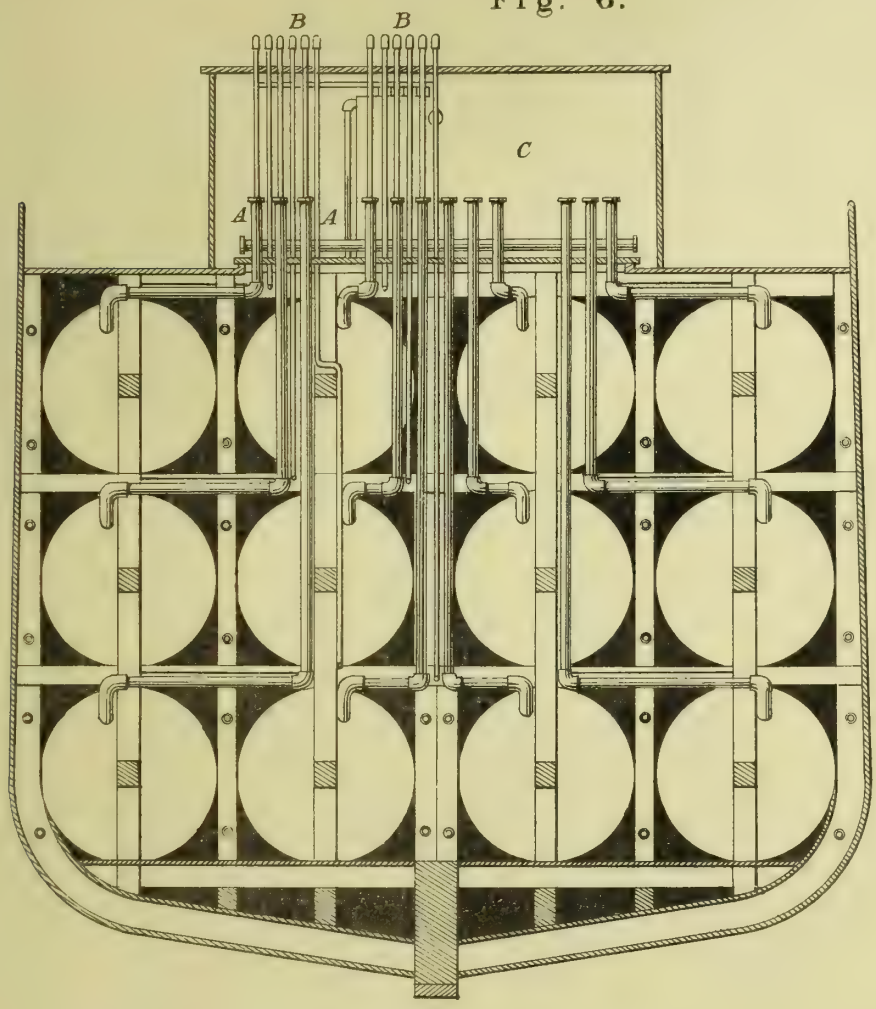
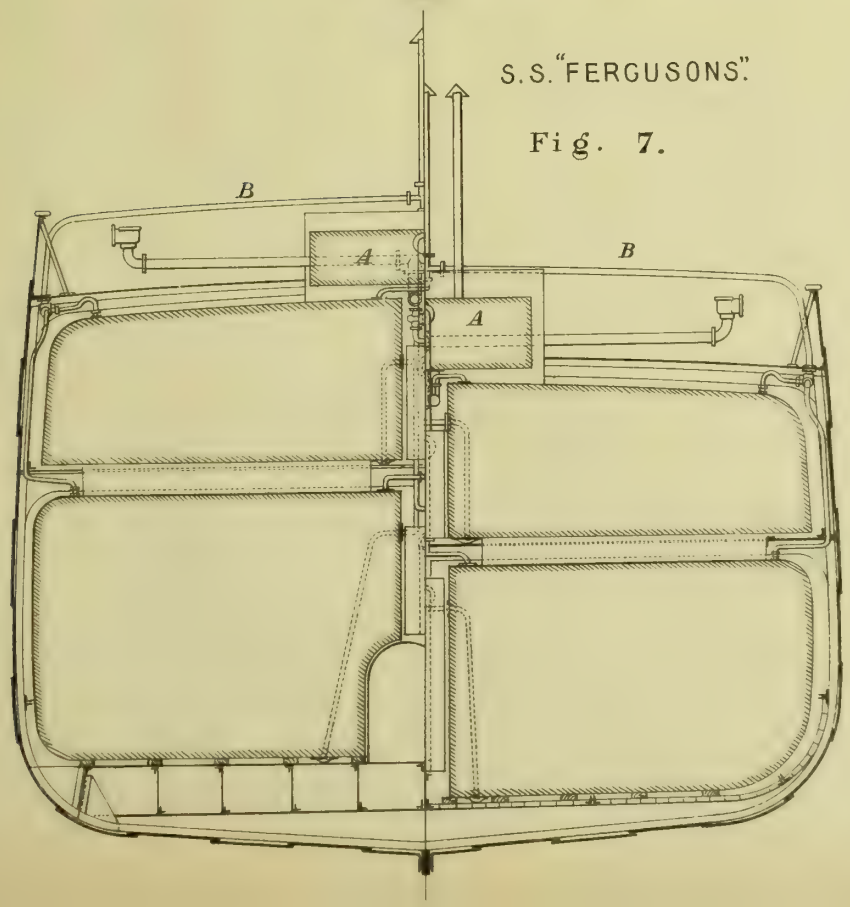
"CRUSADER".

Fig. 6.



S.S. "FERGUSONS".

Fig. 7.



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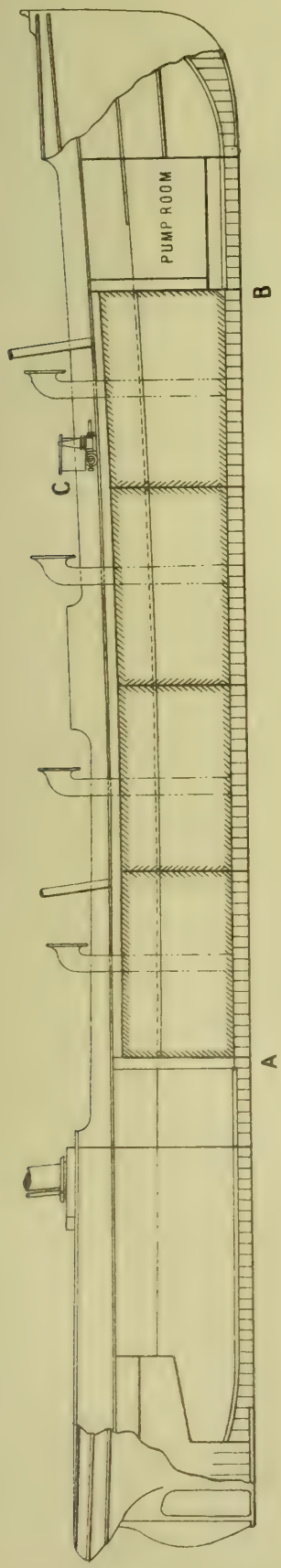


FIG. 9.
S. S. "SVIET."

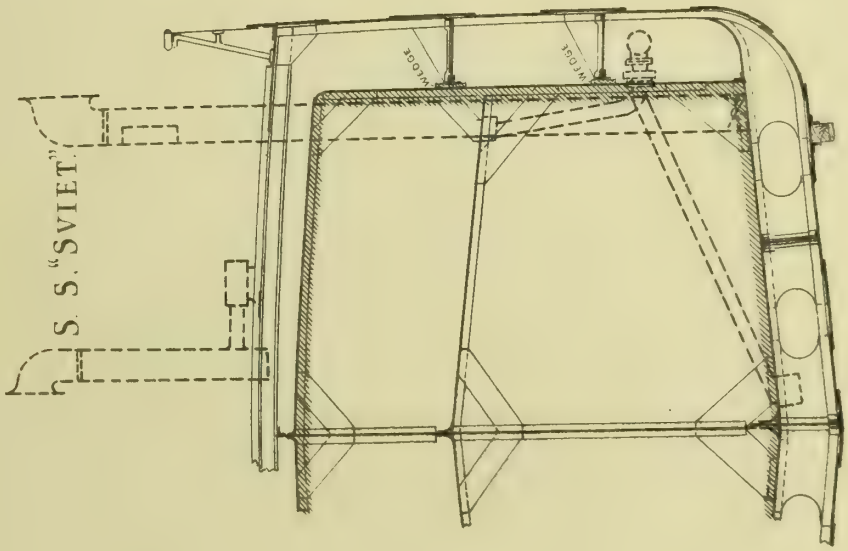
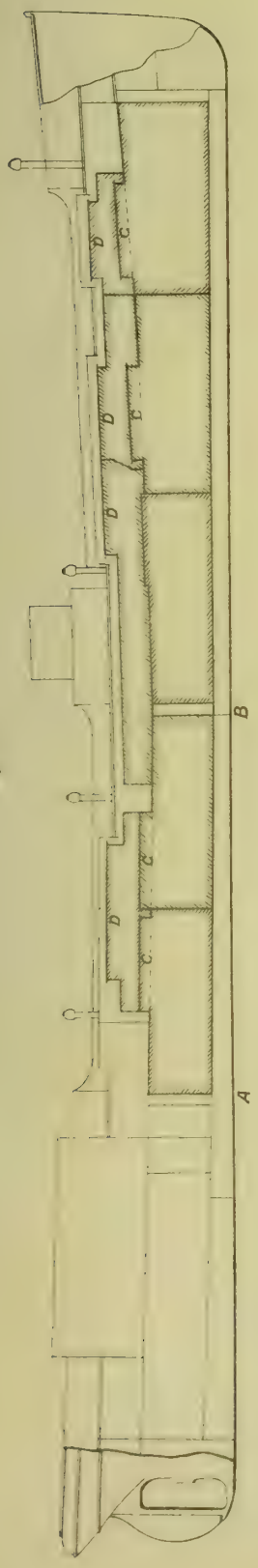


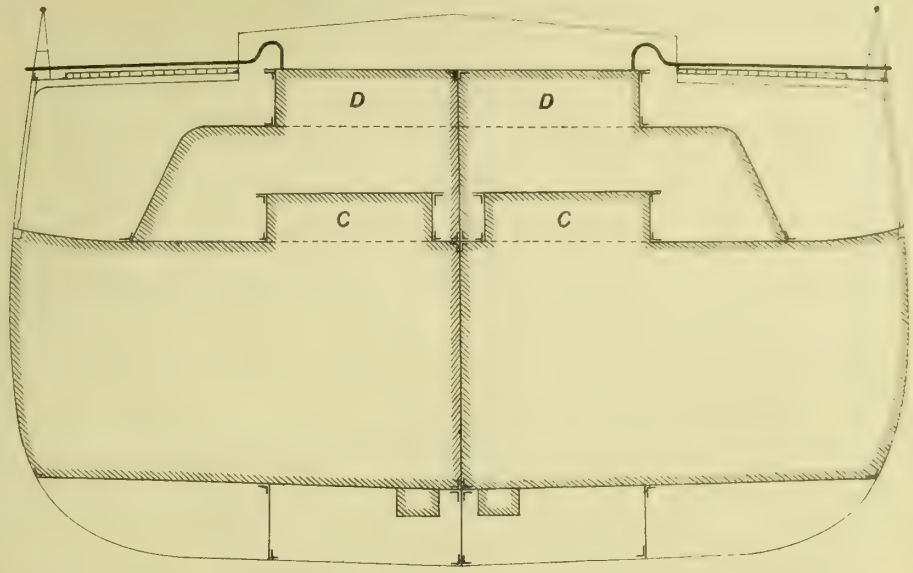
FIG. 8.

To Illustrate Mr. B. Martell's Paper on the Carriage of Petroleum in Bulk on Over-sea Voyages.

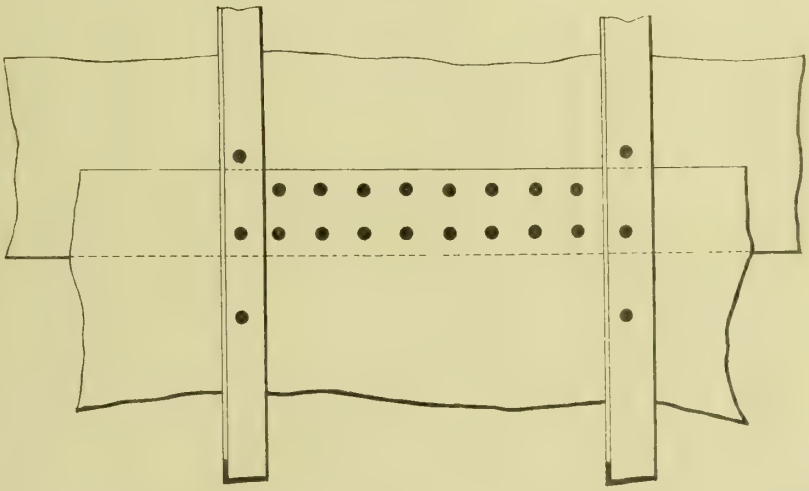
S. S. "BAKUIN".
Fig. 11.



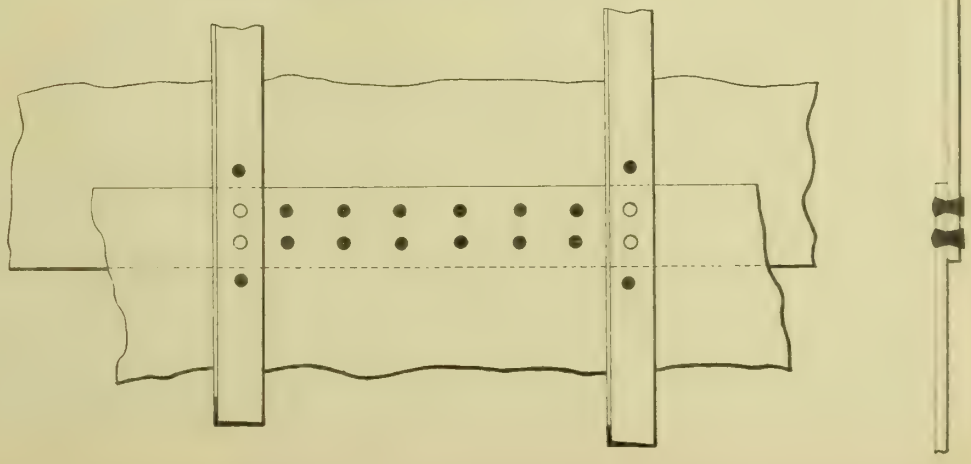
S. S. "BAKUIN".
Fig. 10.



Spacing of Rivets S. S. "BAKUIN".
Fig. 12.



Spacing of Rivets S. S. "CHIGWELL"



To Illustrate Mr. B. Martell's Paper on the Carriage of Petroleum in Bulk on Over-sea Voyages.

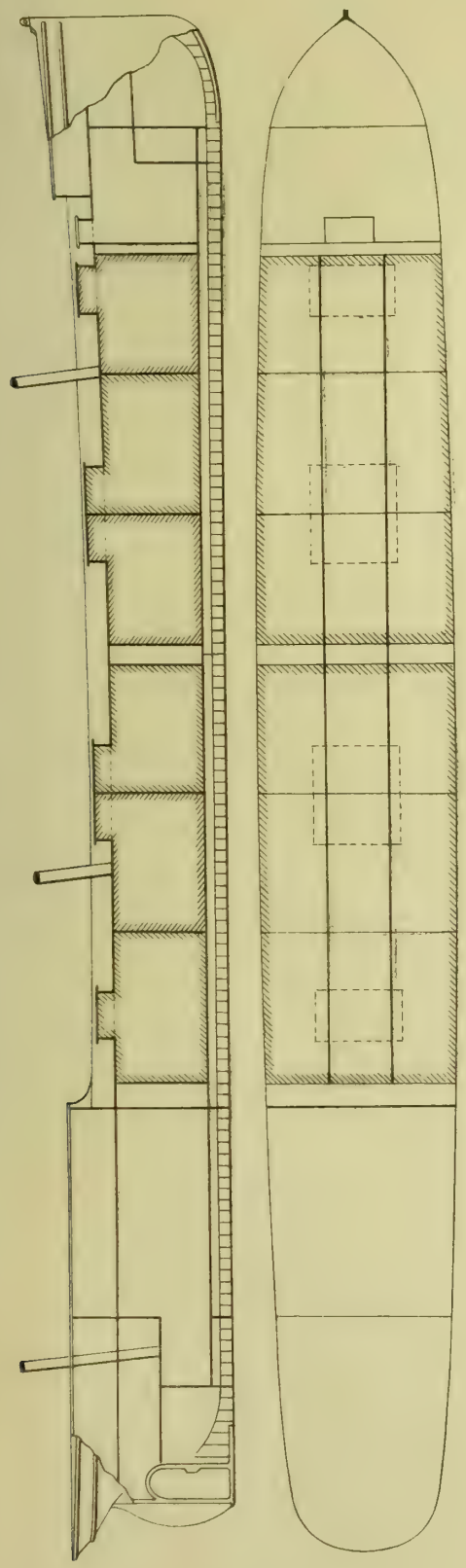


FIG. 14.

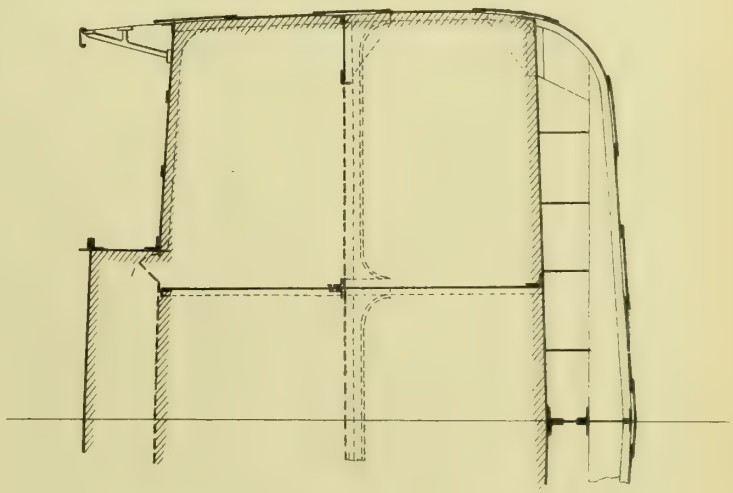


FIG. 13.

To Illustrate Mr. B. Martell's Paper on the Carriage of Petroleum in Bulk on Over-sea Voyages.

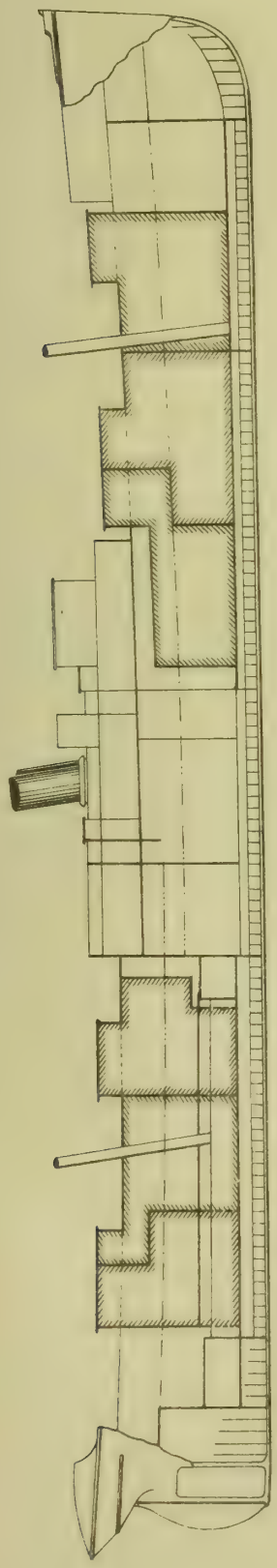
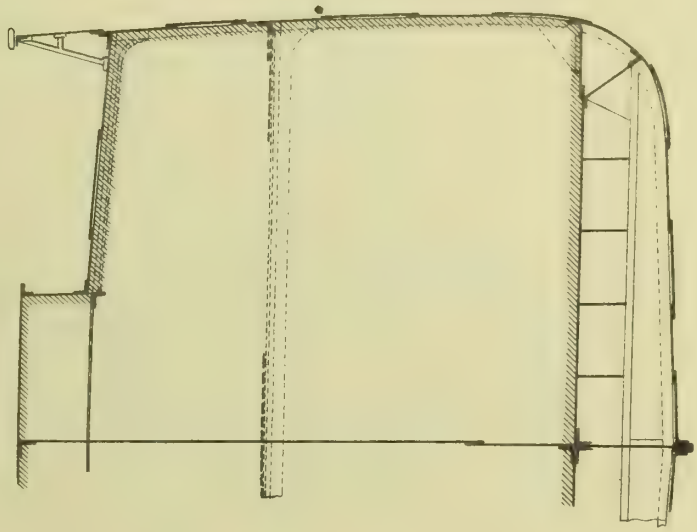


FIG. 16.

S. S. "CHIGWELL".

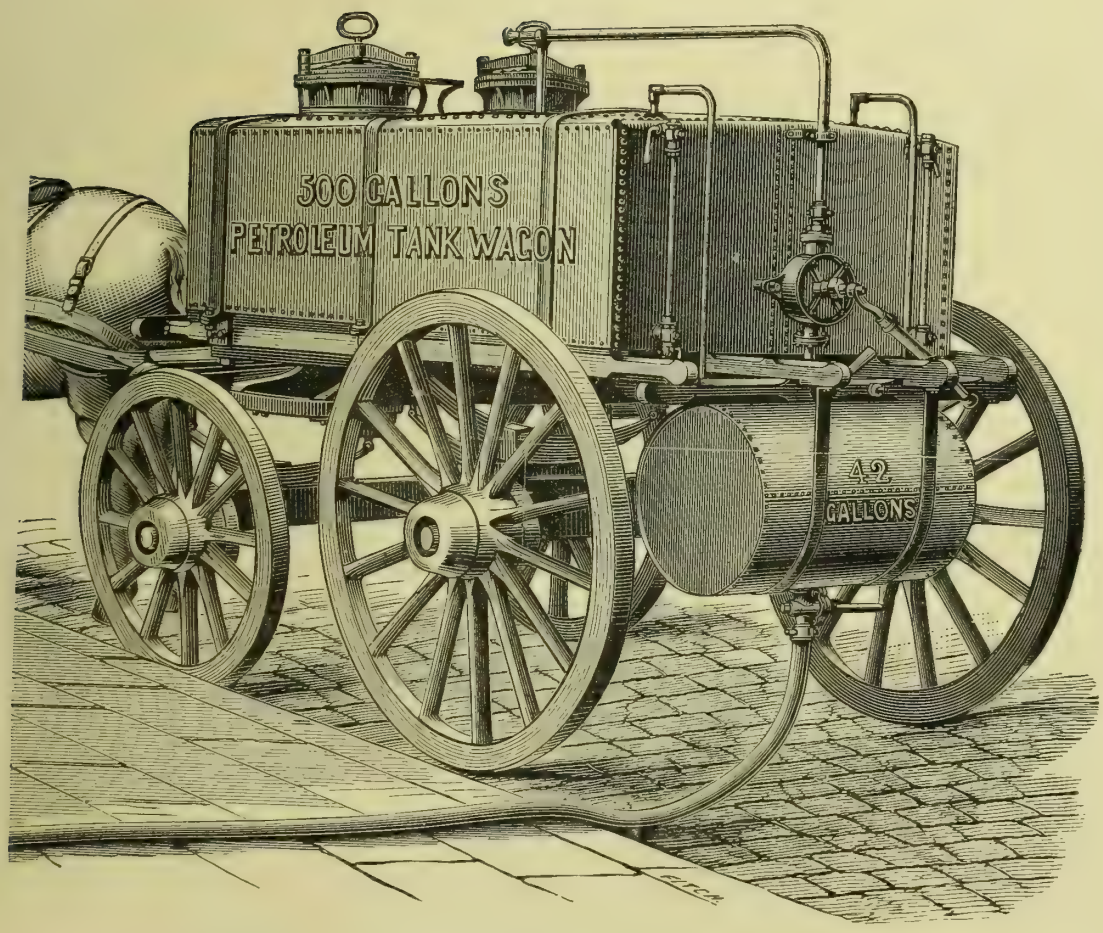


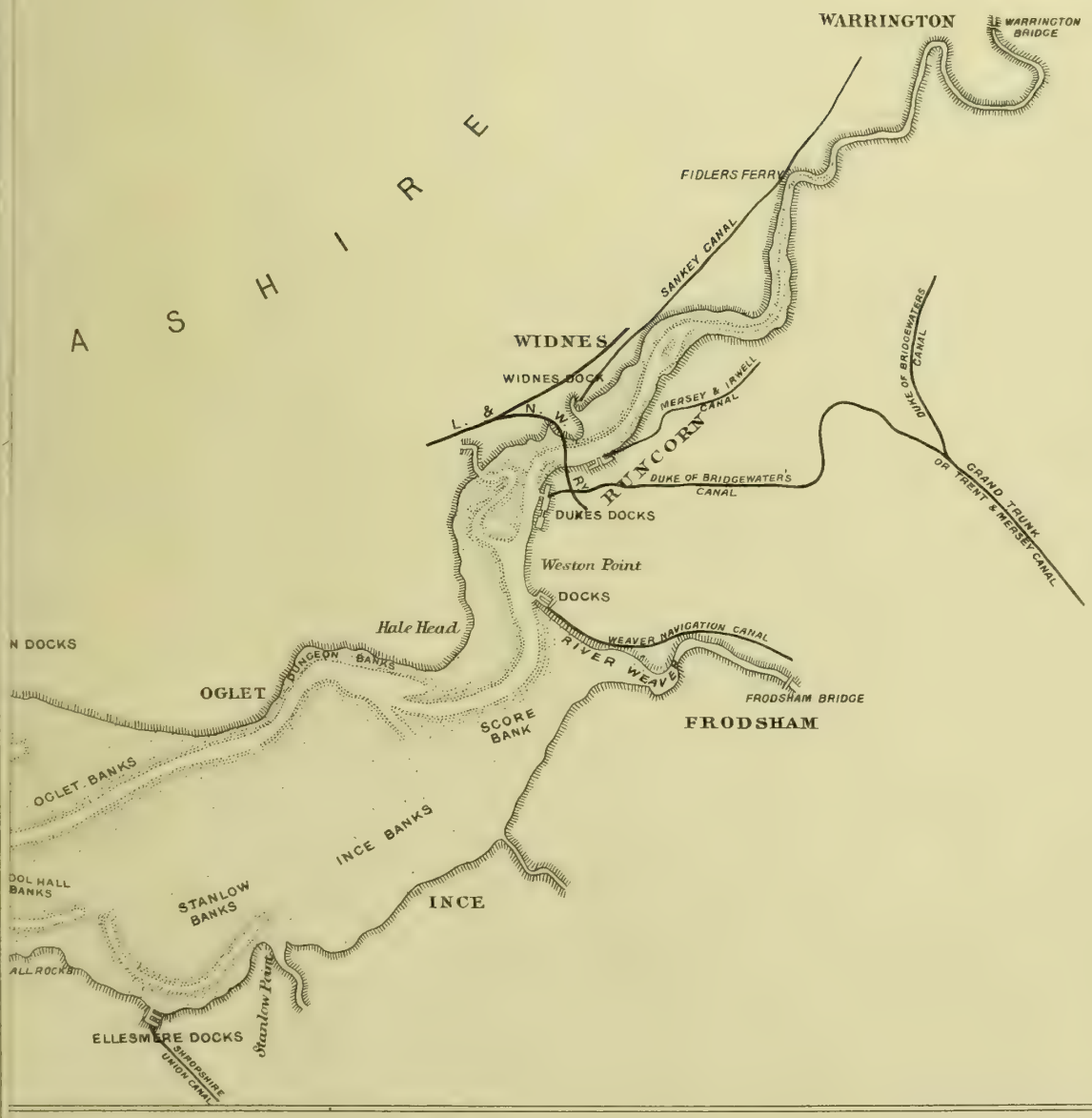
S. S. "CHIGWELL".

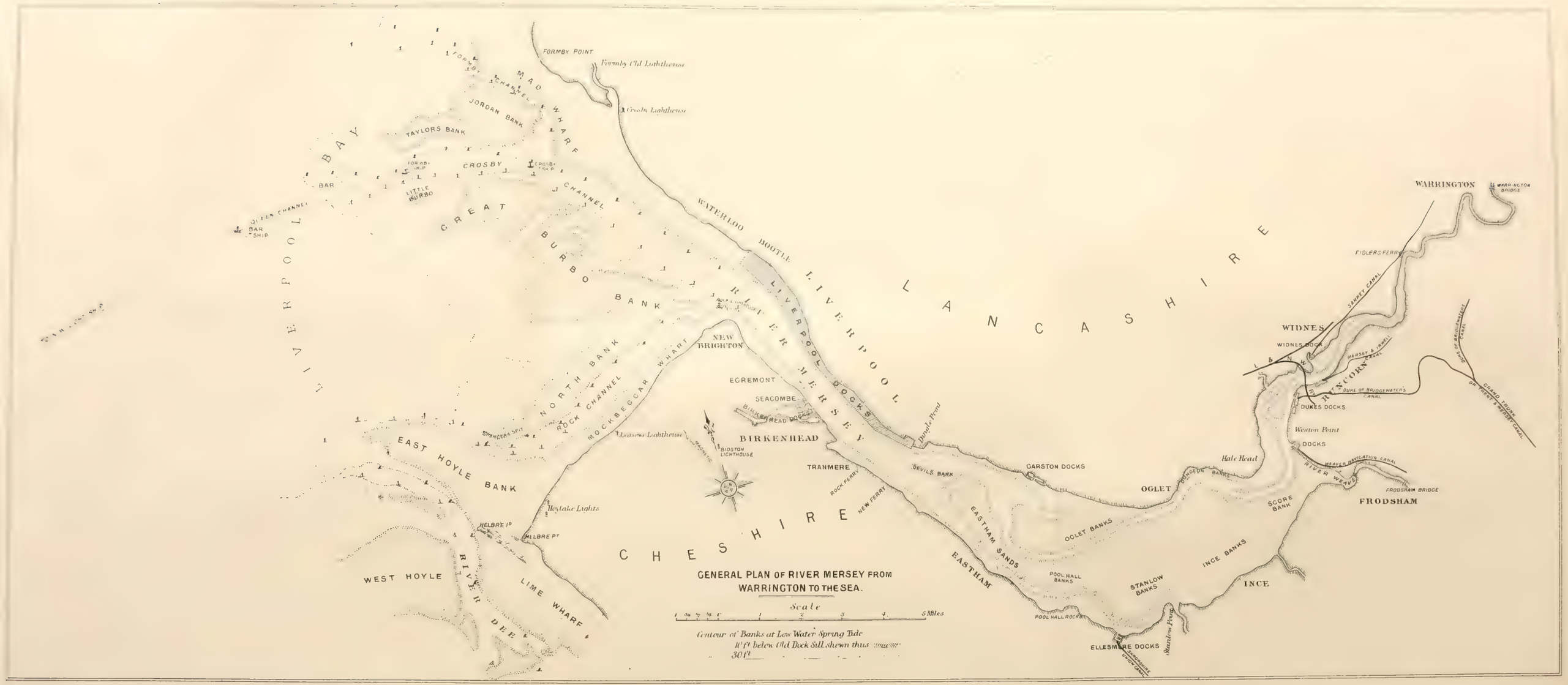
FIG. 15.

To Illustrate Mr. B. Martell's Paper on the Carriage of Petroleum in Bulk on Over-sea Voyages.

Fig. 17.




WARRINGTON
WARRINGTON BRIDGE
A S H I R E
FIDLERS FERRY
SANKEY CANAL
WIDNES
WIDNES DOCK
L. & N. W. R.
MERSEY & IRWELL CANAL
RUNCORN
DUKE OF BRIDGEWATER'S CANAL
DUKES DOCKS
DUKE OF BRIDGEWATERS CANAL
GRAND TRUNK OR TRENT & MERSEY CANAL
Weston Point
DOCKS
WEAVER NAVIGATION CANAL
RIVER WEAVER
FRODSHAM BRIDGE
FRODSHAM
Hale Head
N DOCKS
DUNGEON BANKS
OGLET
SCORE BANK
OGLET BANKS
INCE BANKS
DOL HALL BANKS
STANLOW BANKS
INCE
ALL ROCKS
Stanlow Point
ELLESMERE DOCKS
SHROPSHIRE UNION CANAL


GENERAL PLAN OF RIVER MERSEY FROM WARRINGTON TO THE SEA.
Scale
5 Miles
Contour of Banks at Low Water Spring Tide
10 ft below Old Dock Sill shewn thus
30 ft
LIVERPOOL BAY
LANCASHIRE
CHESHIRE
FORMBY POINT
Formby Old Lighthouse
Crosby Lighthouse
FORMBY CHANNEL
MAD WHARF
JORDAN BANK
TAYLORS BANK
CROSBY
BAR
LITTLE BURBO
QUEEN CHANNEL
BAR SHIP
GREAT BURBO BANK
CHANNEL
WATERLOO
BOOTLE
LIVERPOOL
LIVERPOOL DOCKS
RIVER MERSEY
NORTH BANK
ROCK CHANNEL
MOCKBEGGAR WHARF
NEW BRIGHTON
EGREMONT
SEACOMBE
BIRKENHEAD DOCKS
BIRKENHEAD
Leasowe Lighthouse
BIDSTON LIGHTHOUSE
MAGNETIC
TRANMERE
ROCK FERRY
NEW FERRY
Dingle Pond
DEVILS BANK
GARSTON DOCKS
OGLET
OGLET BANKS
EASTHAM SANDS
EASTHAM
POOL HALL BANKS
POOL HALL ROCK
STANLOW BANKS
Stanlow Point
ELLESMERE DOCKS
MANCHESTER SHIP CANAL
INCE BANKS
INCE
SCORE BANK
Hale Head
RIVER WEAVER
WEAVER NAVIGATION CANAL
FRODSHAM BRIDGE
FRODSHAM
DUKES DOCKS
Weston Point
DOCKS
DUKE OF BRIDGEWATER'S CANAL
RUNCORN
MERSEY & IRWELL CANAL
WIDNES DOCK
WIDNES
SANKEY CANAL
FIDLERS FERRY
WARRINGTON
WARRINGTON BRIDGE
GRAND TRUNK OR TRENT & MERSEY CANAL
DUKE OF BRIDGEWATER'S CANAL
SPENCERS SPIT
EAST HOYLE BANK
Heyslake Lights
HELBRE Id
HILBRE Pt
WEST HOYLE
LIME WHARF
RIVER DEE

PLAN
OF THE
LIVERPOOL AND BIRKENHEAD DOCKS.
1886.
Engineer.

To Illustrate Mr. G. Fosbery Lyster's Paper on a Description of the River Mersey and the Port of Liverpool.

To Illustrate Mr. F. Elgar's Paper on Notes upon Losses at Sea.

Fig. 1.

Curves illustrating the effect of an increase of freeboard upon stability, the cargo being supposed to fill the vessel; and also the effect of variation in the density of the cargo.

A—Curve of stability of a steamer (298 feet × 32·1 feet × 22 feet) *filled* with homogeneous cargo, and having a freeboard of 4 feet 7 inches. (The cargo would occupy 61·2 cubic feet per ton of weight.)

B—Curve of stability for the same vessel *filled* with homogeneous cargo, and having a freeboard of 5 feet 1 inch. (The cargo would occupy 65·5 cubic feet per ton.)

C—Curve of stability for the same vessel laden with cargo of the same density as in *A*, but having a freeboard of 5 feet 1 inch; *spaces* in the 'tween decks at the ends of the vessel being left empty.

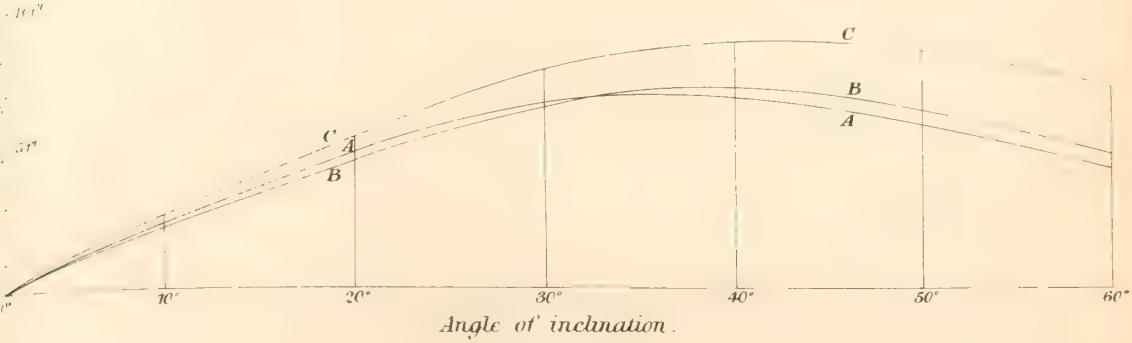


Fig. 2.

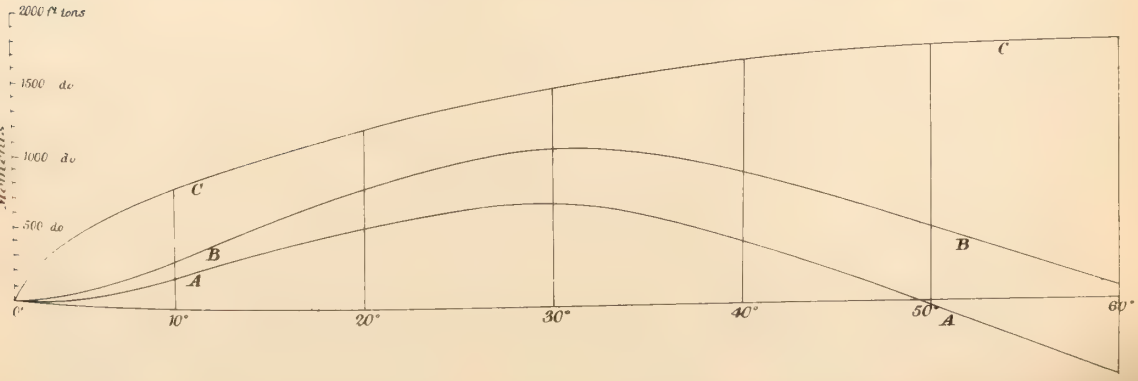
Curves illustrating the effect upon stability of the settling down of a homogeneous cargo in a steamer, and the heeling moments that would be caused by the cargo moving over so as to keep the surface of the cargo parallel to that of the water during inclination.

Dimensions of vessel	282·8 feet × 33·3 feet × 24·2 feet.
Displacement	4,193 tons.
Weight of cargo required to bring vessel to load draught	2,565 tons.

A—Curve of righting moments when holds and 'tween decks are all full up to deck. (The cargo would occupy 49·6 cubic feet per ton of weight.)

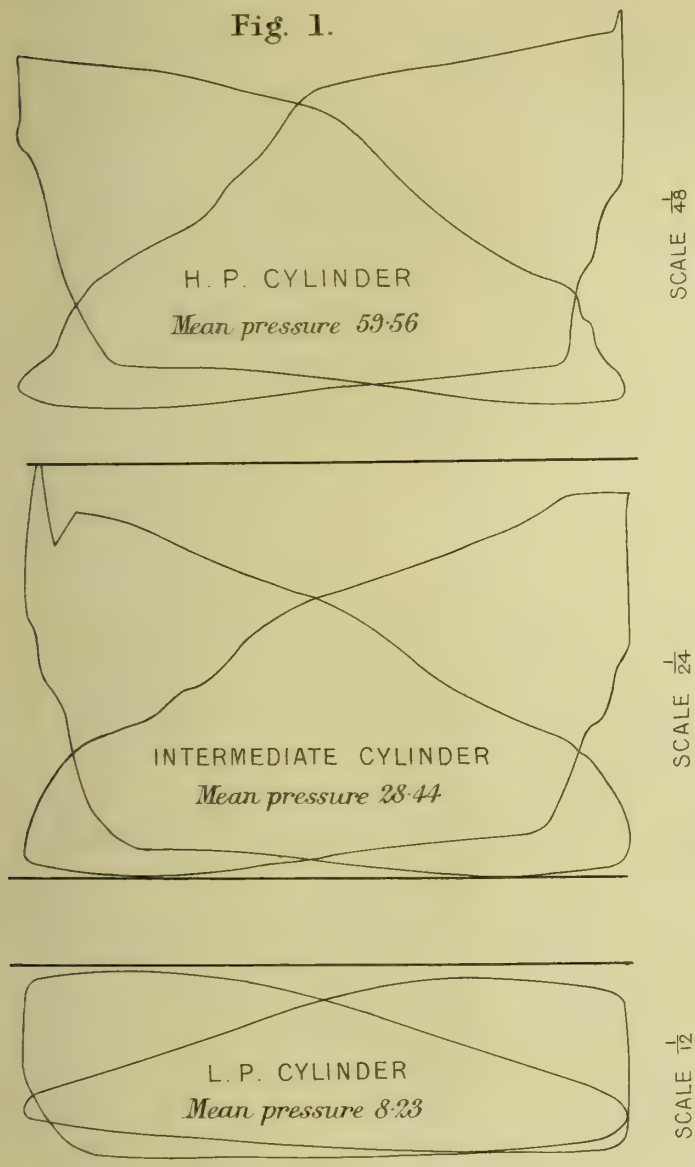
B—Curve of righting moments supposing cargo in holds to settle down 1 foot, and cargo in 'tween decks to settle down 6 inches.

C—Curve of heeling moments that would be caused by the shifting of cargo that the empty spaces allowed for in *B* would admit of as the ship inclines.



To Illustrate Mr. W. Parker's Paper on the Progress and Development of Marine Engineering.

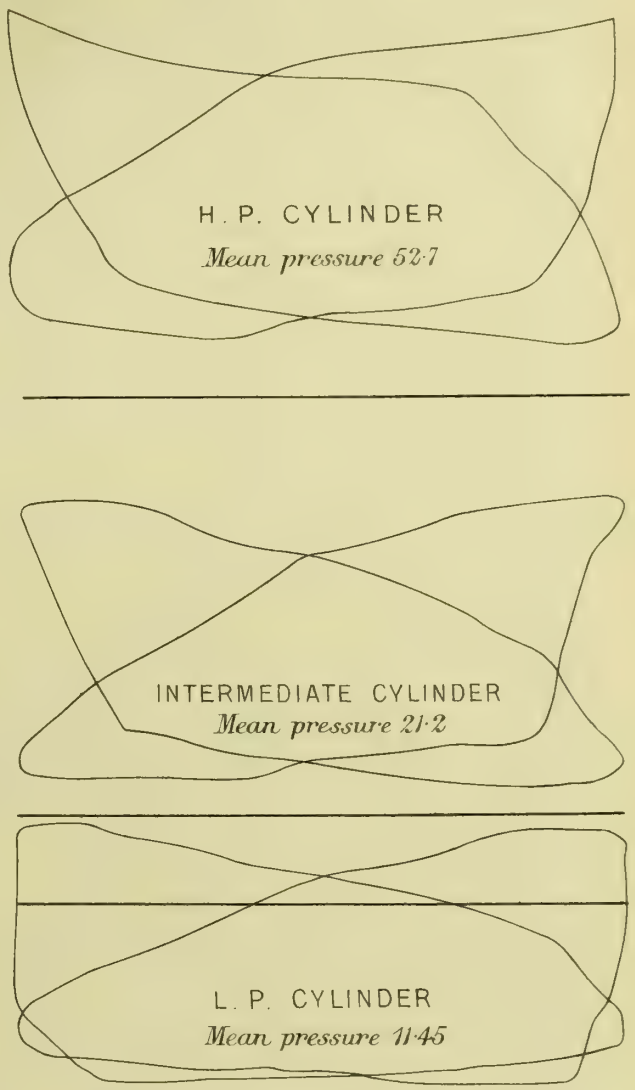
Fig. 1.



Steam Pressure 150 lbs.
Ratio of Cylinders: 1 : 2·5 : 7·11

Mean pressure of three Cylinders reduced to low pressure Cylinder 25·61 lbs. per Sq. Inch.

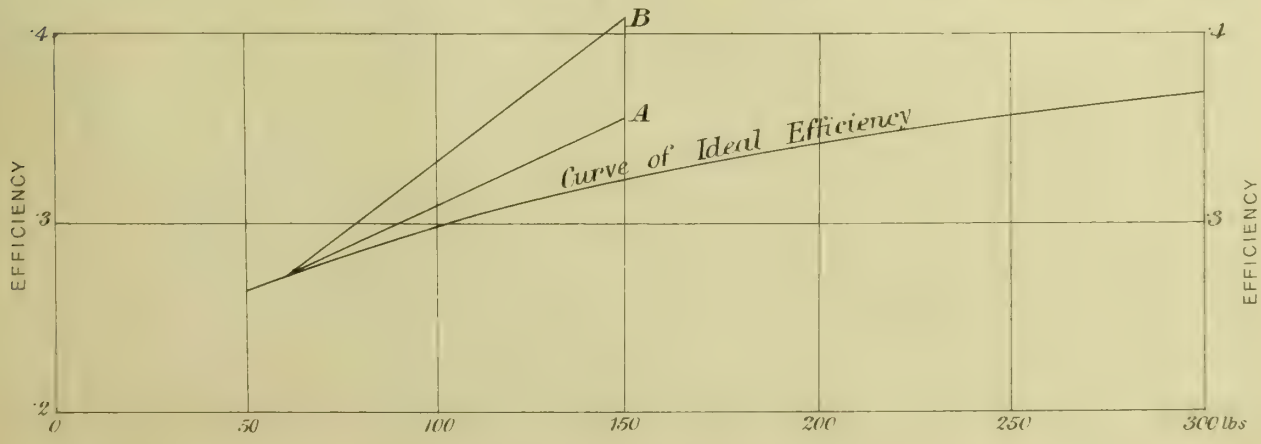
Fig. 2.



Steam Pressure 135 lbs.
Ratio of Cylinders: 1 : 2·5 : 5·28

Mean pressure of three Cylinders reduced to low pressure Cylinder 32·10 lbs. per Sq. Inch.

Fig. 3.



Steam Pressures above Atmosphere.

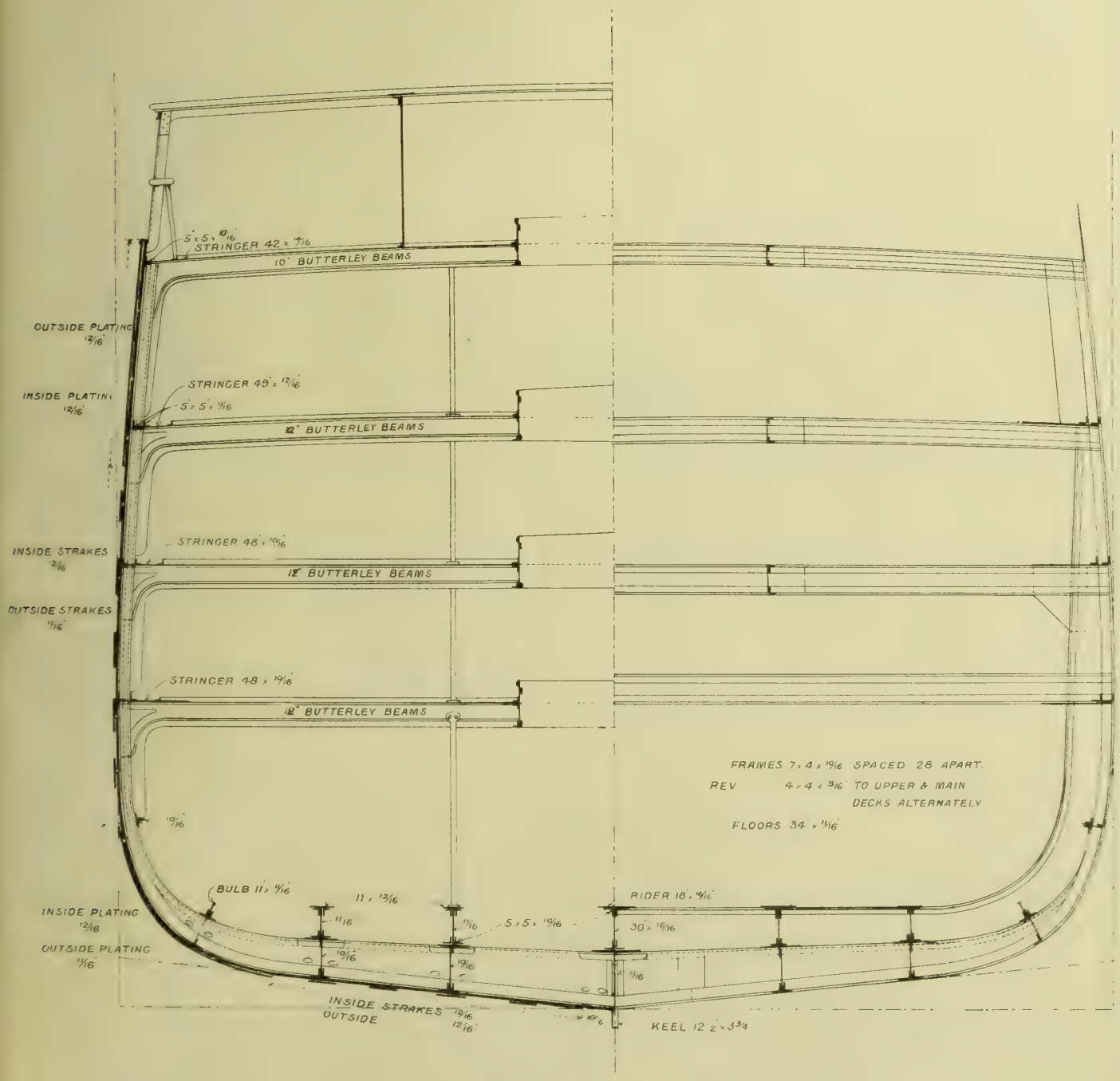
To Illustrate Mr. W. John's Paper on Atlantic Passenger Steamers.

S.S. "CITY OF ROME."

MIDSHIP SECTION.

546′ × 52′ × 37′ HOLD.

SCALE ½″ = 1 FOOT.



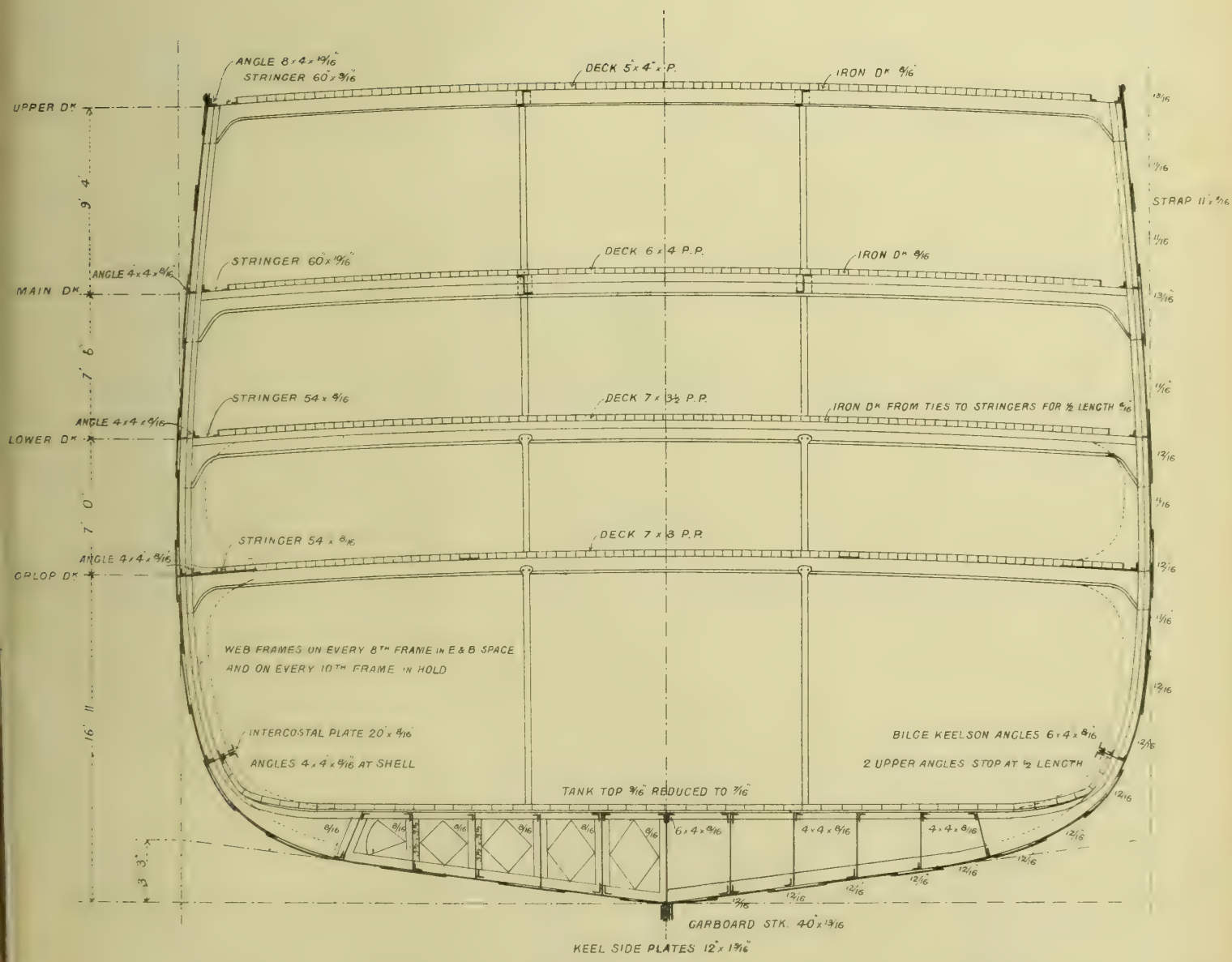
To Illustrate Mr. W. John's Paper on Atlantic Passenger Steamers.

S.S. "SERVIA."

MIDSHIP SECTION.

S.S. 500′ × 50 × 40·9 M. D.

SCALE $\frac{1}{8}$″ = 1 FOOT.



FRAMES FROM OUTER EDGE OF TANK TO UPPER DECK, 7 × 3½ × $\frac{8}{16}$ FOR 250 FT. AMIDSHIPS, FOR 60 FT. BEFORE AND ABAFT THESE POINTS 6½ × 3½ × $\frac{6}{16}$ AT END OF VESSEL 5 × 3½ × $\frac{7}{16}$, ALL SPACED 24 IN. APART AND ALL CARRIED TO UPPER DECK, DOUBLE FROM BILGE TO BILGE IN WAY OF ENGINES.

FRAMES IN TANK ON LATICE AND SOLID FLOORS, 5 × 3½ × $\frac{8}{16}$, INTERMEDIATE FRAMES, 8 × 4 × $\frac{8}{16}$.

REV: FRAMES, 4½ × 3½ × $\frac{8}{16}$, CARRIED TO UPPER AND MAIN DECK ALTERNATELY, DOUBLE, 4½ × 4½ × $\frac{8}{16}$ FROM BILGE TO BILGE IN E AND B SPACE.

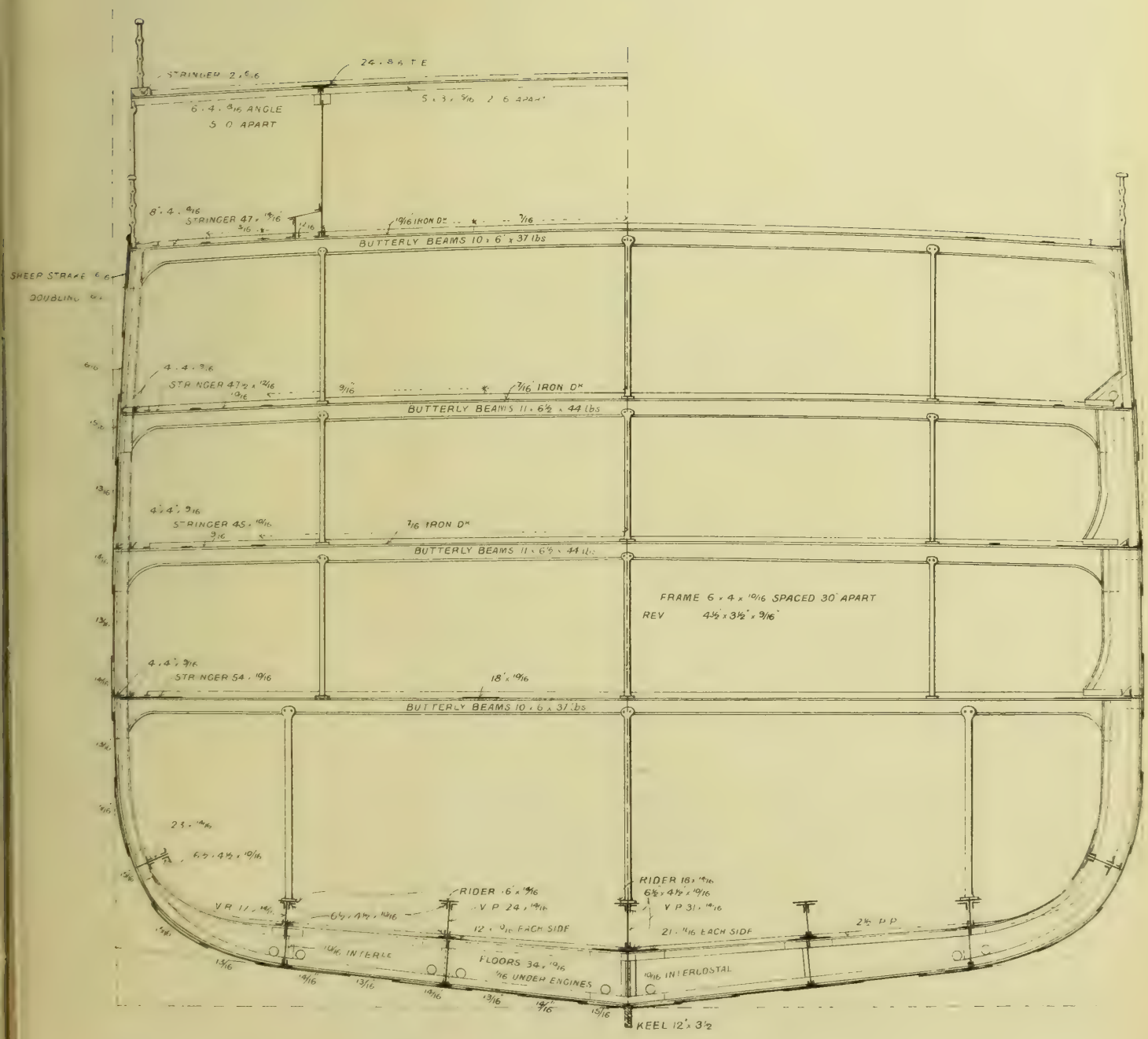
To Illustrate Mr. W. John's Paper on Atlantic Passenger Steamers.

S.S. "OREGON."

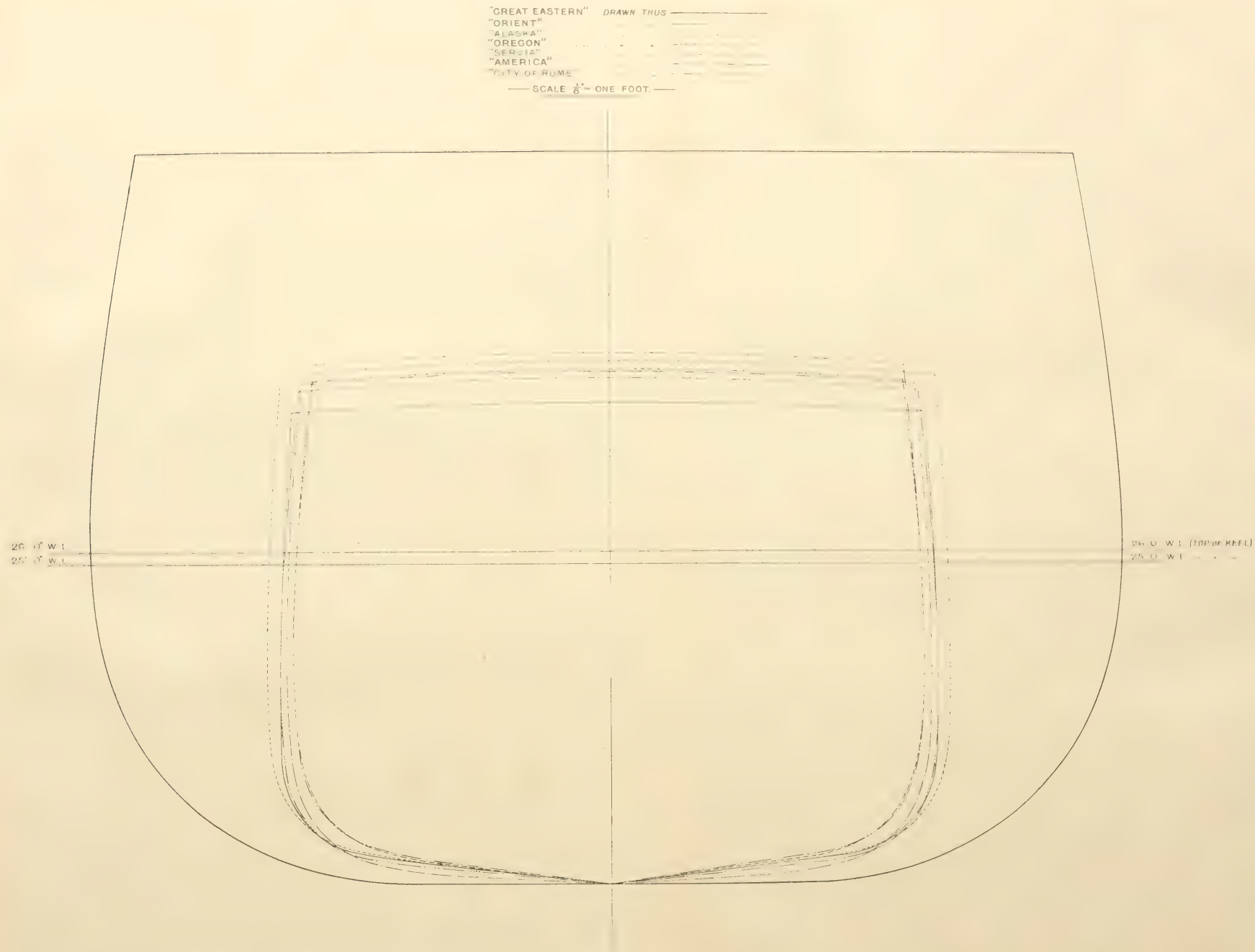
MIDSHIP SECTION.

500′ × 54′ × 38′ HOLD.

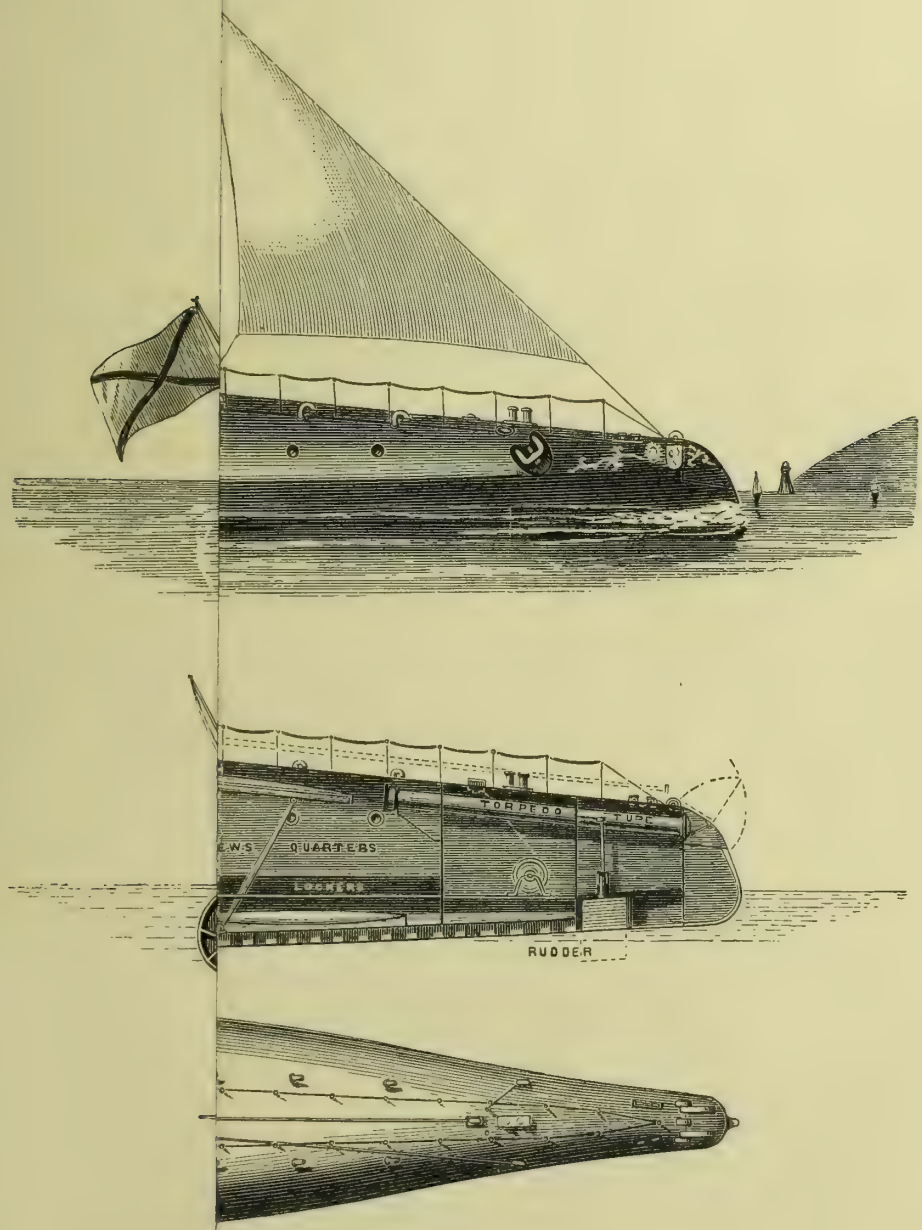
SCALE ½″ = 1 FOOT



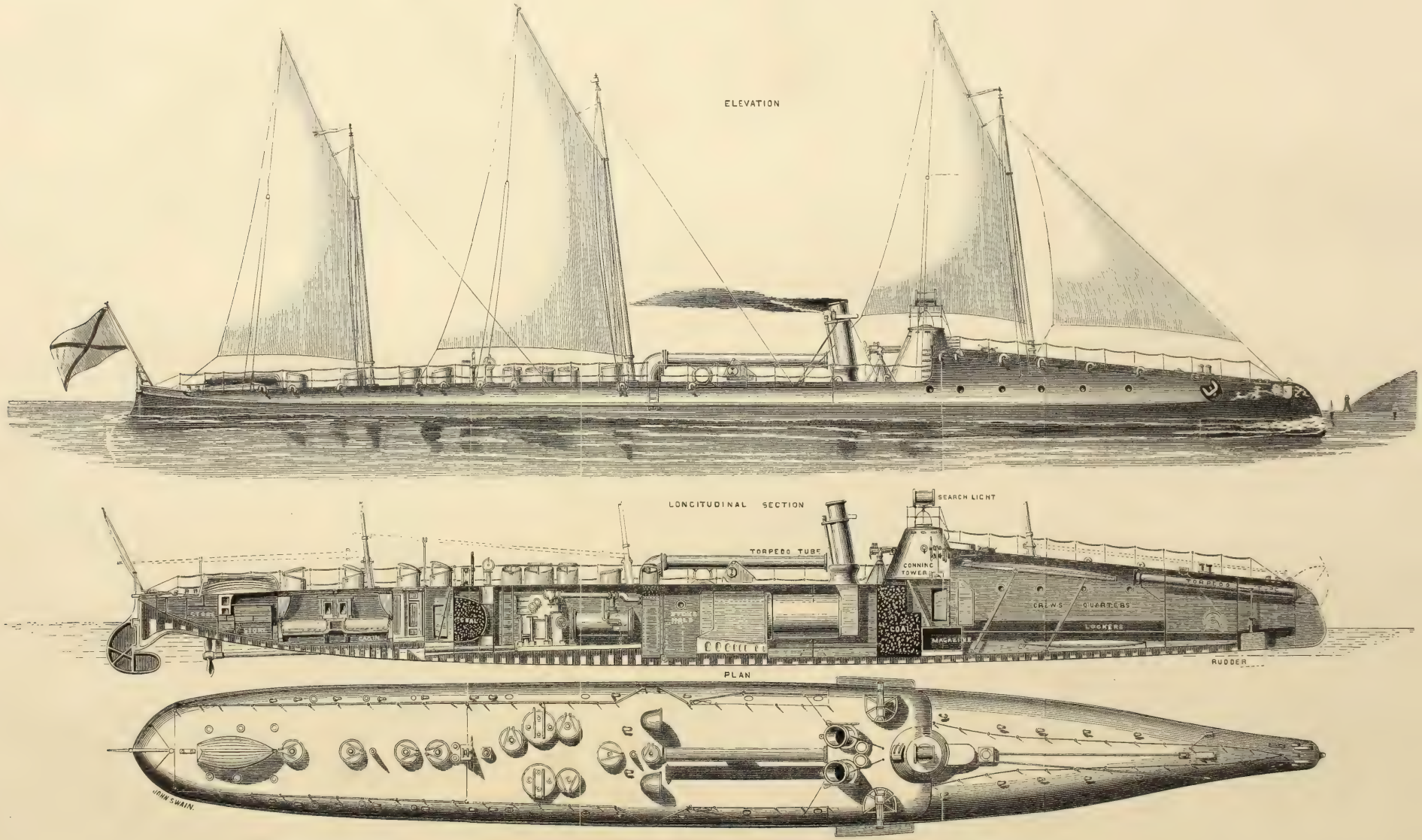
To Illustrate Mr. W. John's Paper on Atlantic Passenger Steamers



El Destructor."



To Illustrate Mr. J. H. Biles's Paper on the Twin Screw Torpedo Vessels "Wiborg" and "El Destructor."



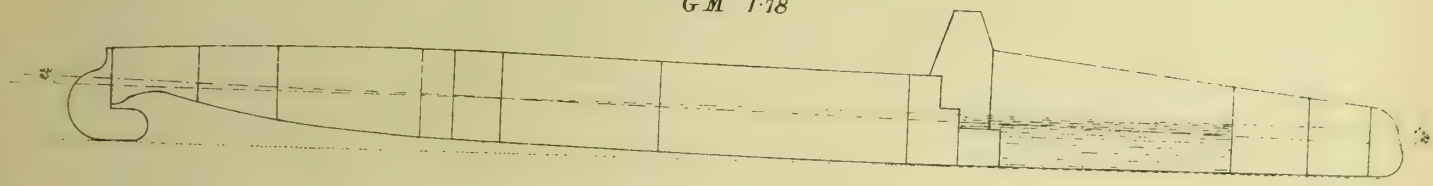
RUSSIAN TWIN-SCREW SEA-KEEPING TORPEDO BOAT.

To Illustrate Mr. J. H. Biles's Paper on the Twin Screw Torpedo Vessels "Wiborg" and "El Destructor."

"WIBORG."

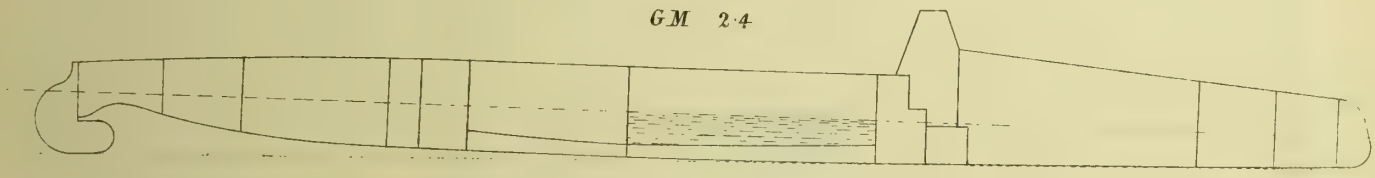
A

GM 1·78



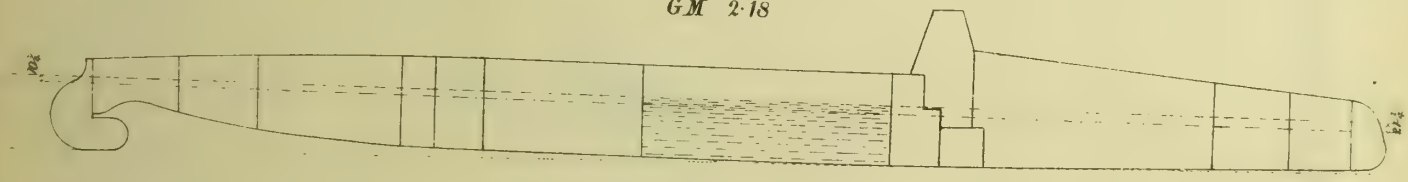
B

GM 2·4



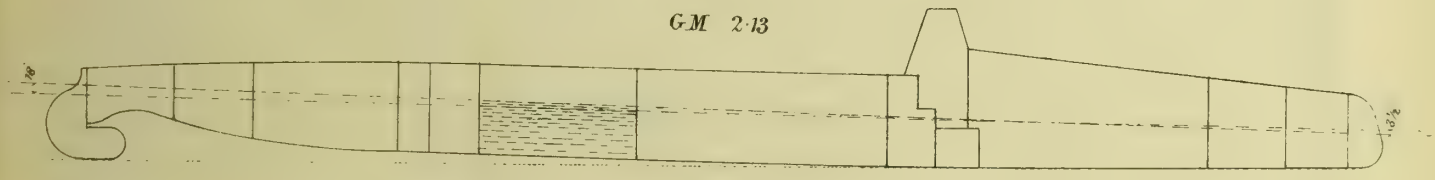
C

GM 2·18



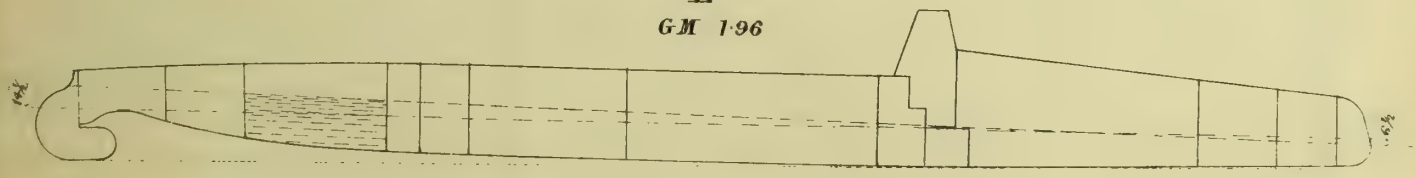
D

GM 2·13

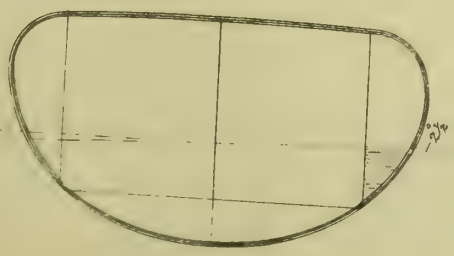


E

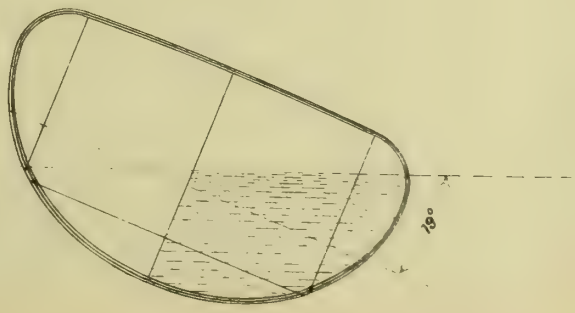
GM 1·96



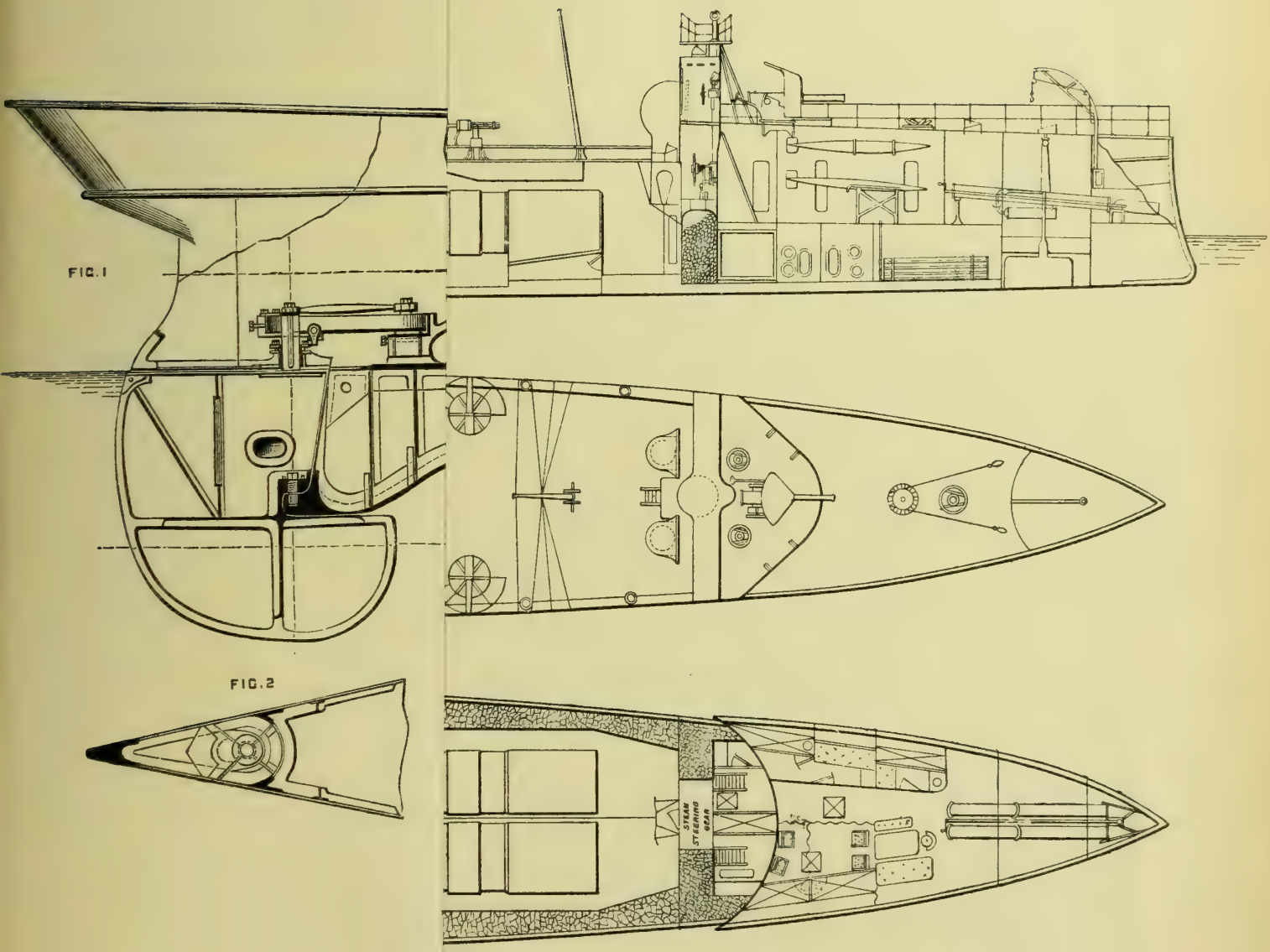
B



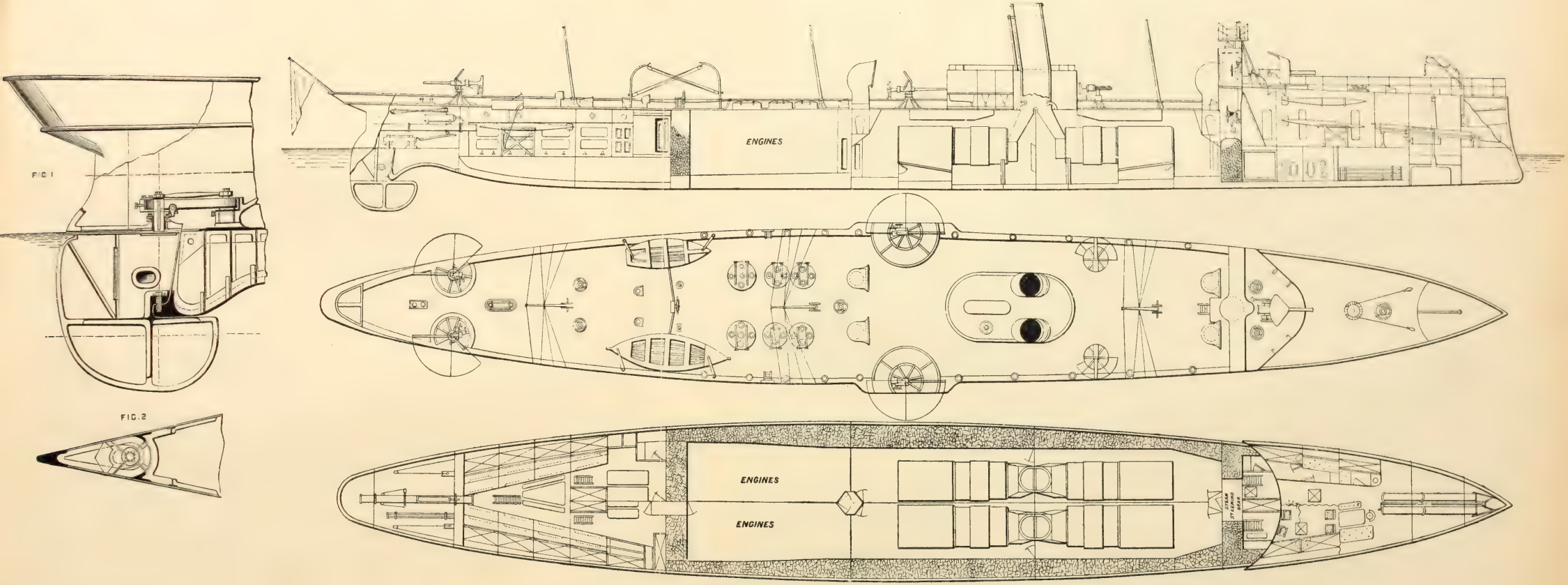
F



l Destructor."



To Illustrate Mr. J. H. Biles's Paper on the Twin Screw Torpedo Vessels "Wiborg" and "El Destructor."

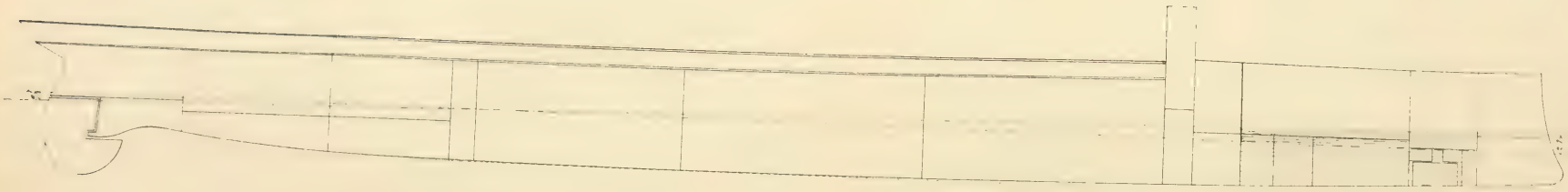


To Illustrate Mr. J. H. Biles's Paper on the Twin Screw Torpedo Vessels "Wiborg" and "El Destructor."

EL. DESTRUCTOR.

D

A



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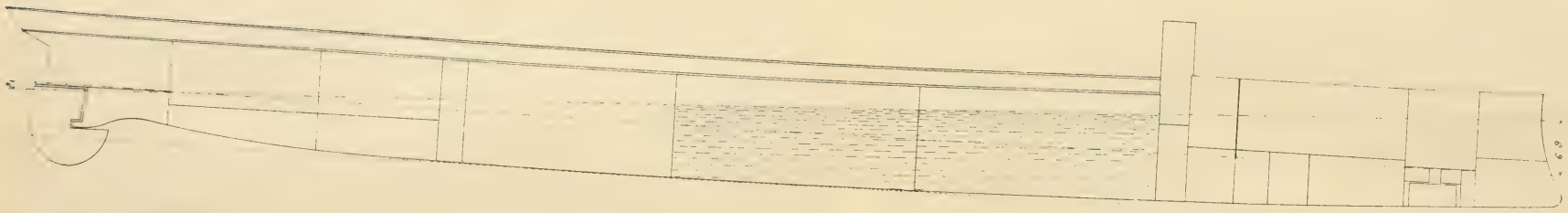
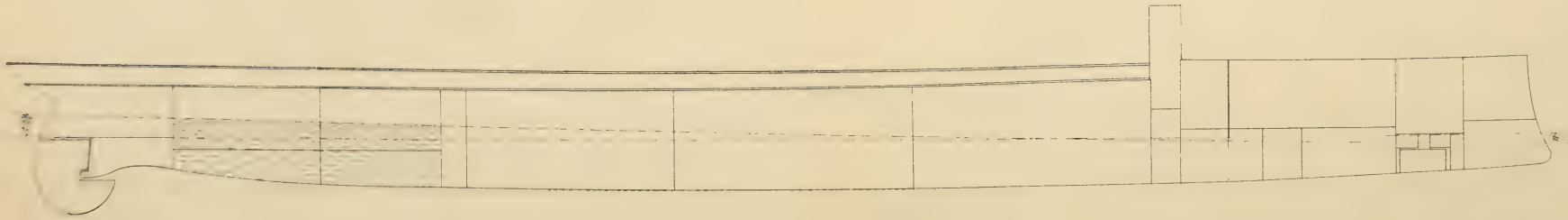


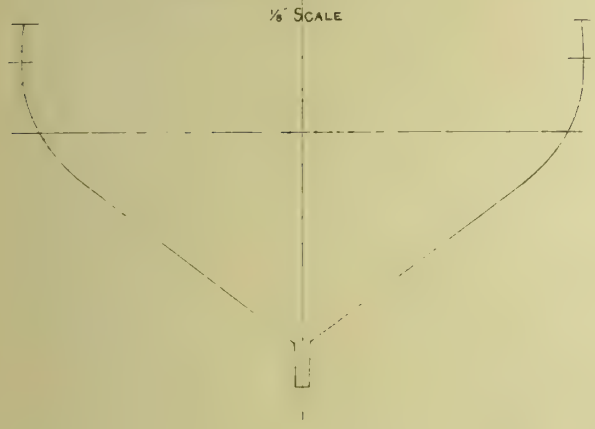
C



To Illustrate Mr. Dixon Kemp's Paper on Fifty Years of Yacht Building.

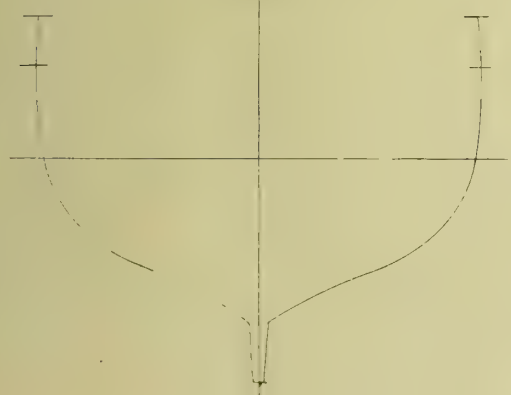
"AMERICA" 1851.

⅛" SCALE



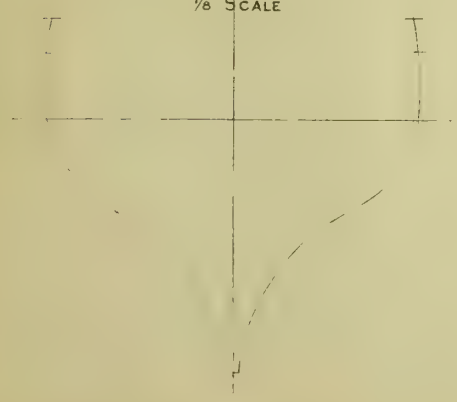
"ARROW" 1822.

⅛" SCALE



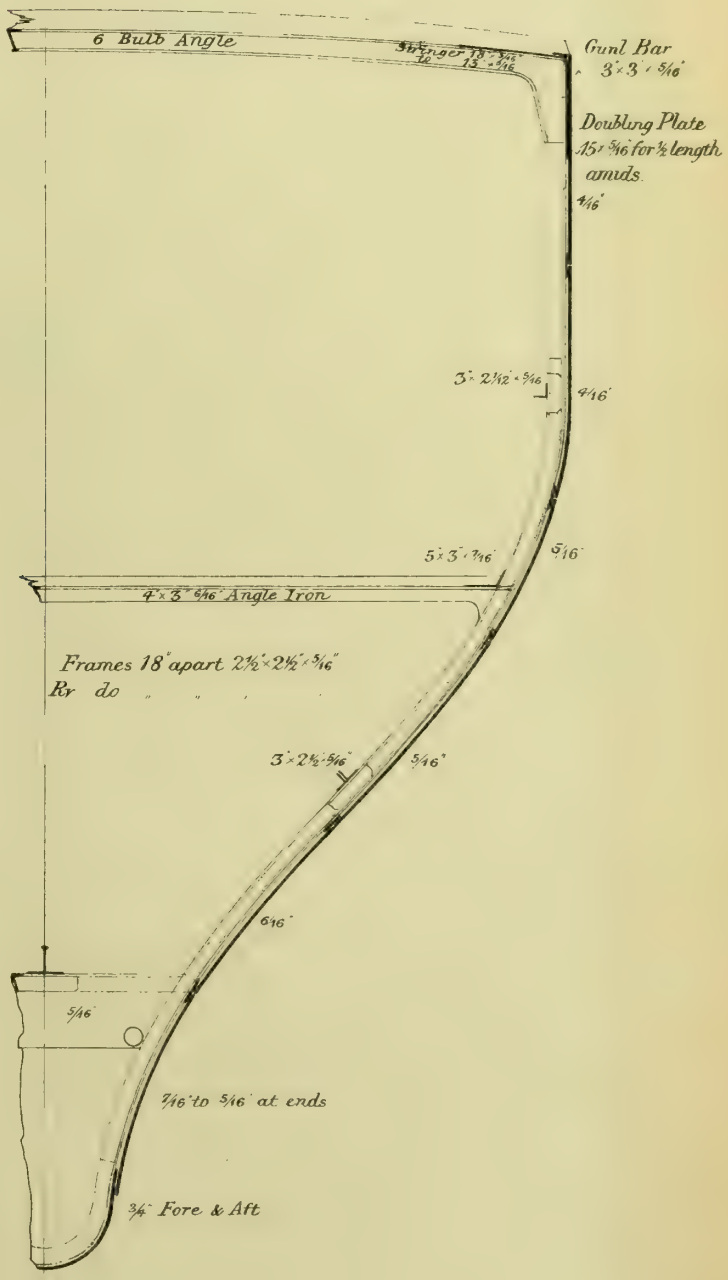
"MOSQUITO" 1847

⅛" SCALE



C. Y. "GALATEA".

SCALE ⅜" = ONE FOOT



LIBRARY
OF THE
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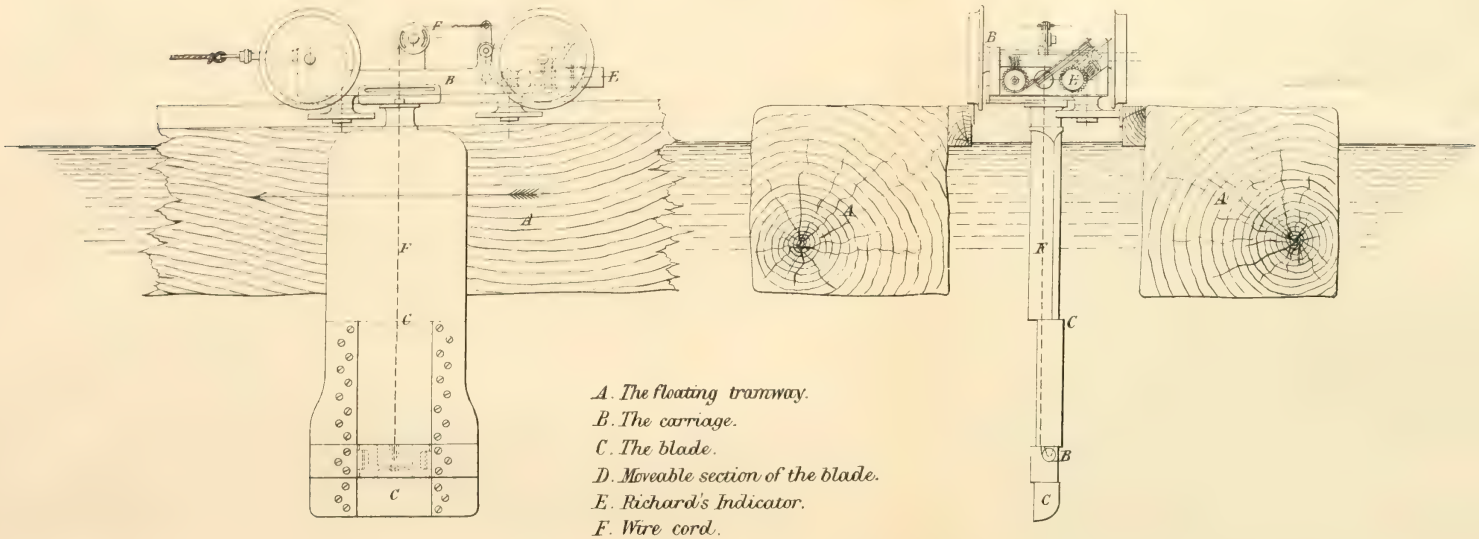
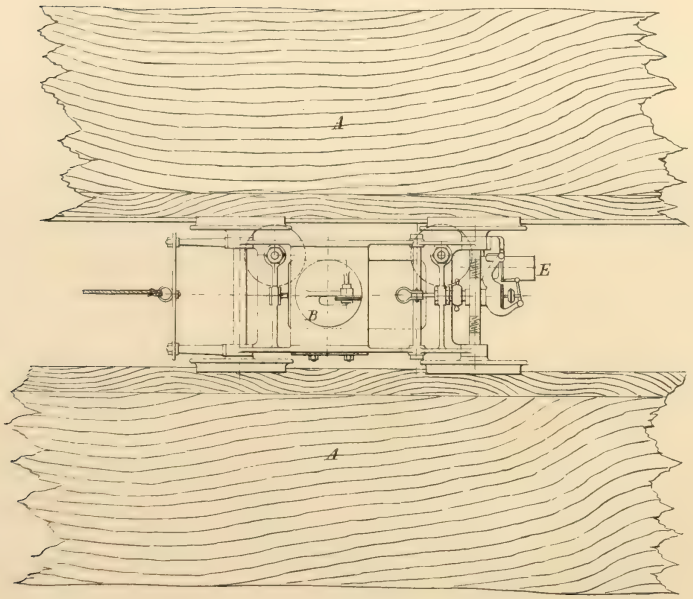
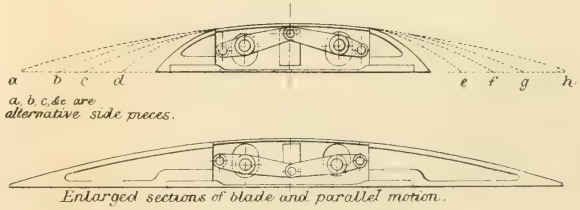
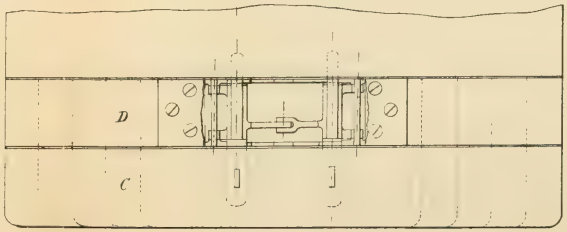
To Illustrate Mr. G. A. Calvert's Paper on the Forces acting on the Blade of a Screw Propeller.

FIG. 1.



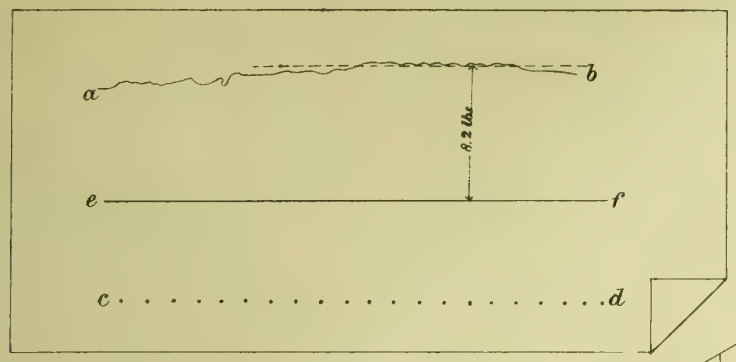






To Illustrate Mr. G. A. Calvert's Paper on the Forces acting on the Blade of a Screw Propeller.

FIG. 2.



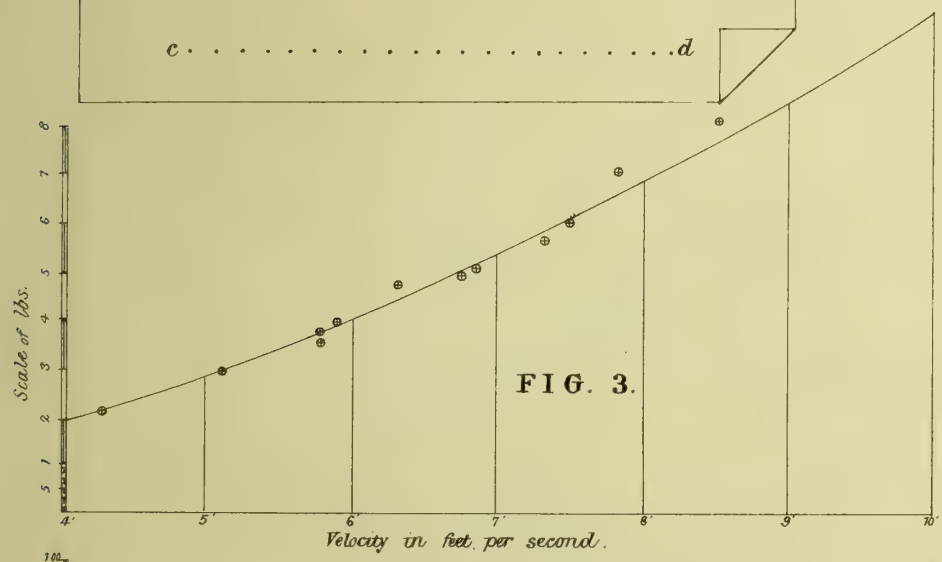


FIG. 3.

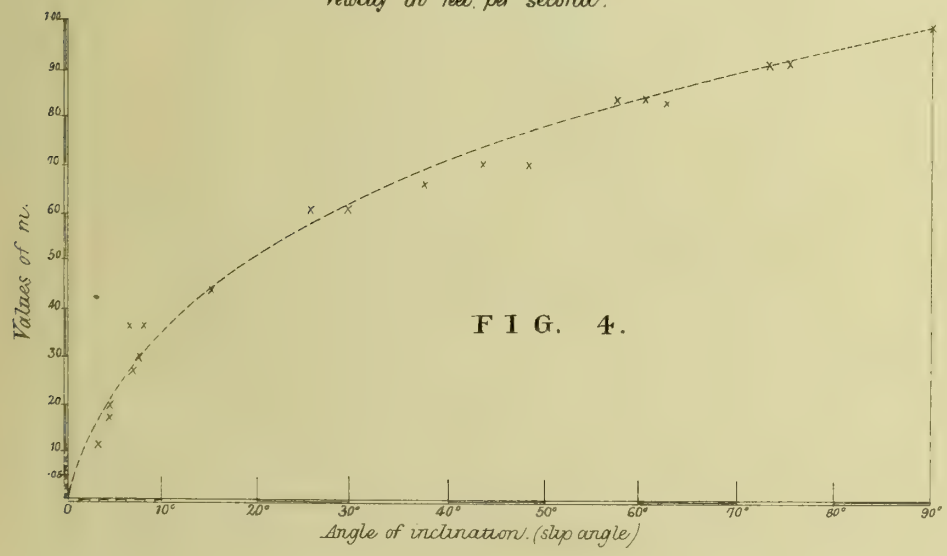


FIG. 4.

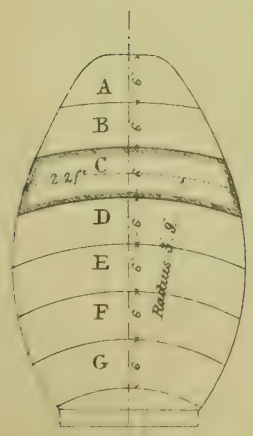


FIG. 5.

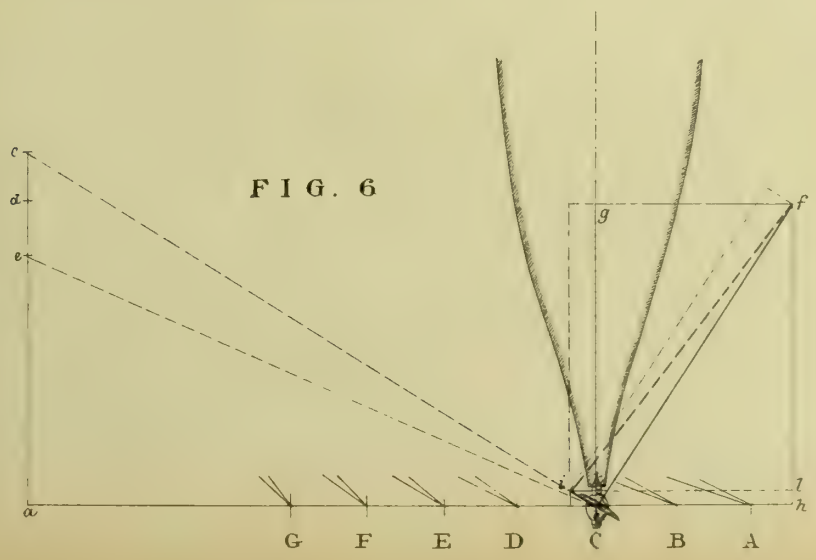
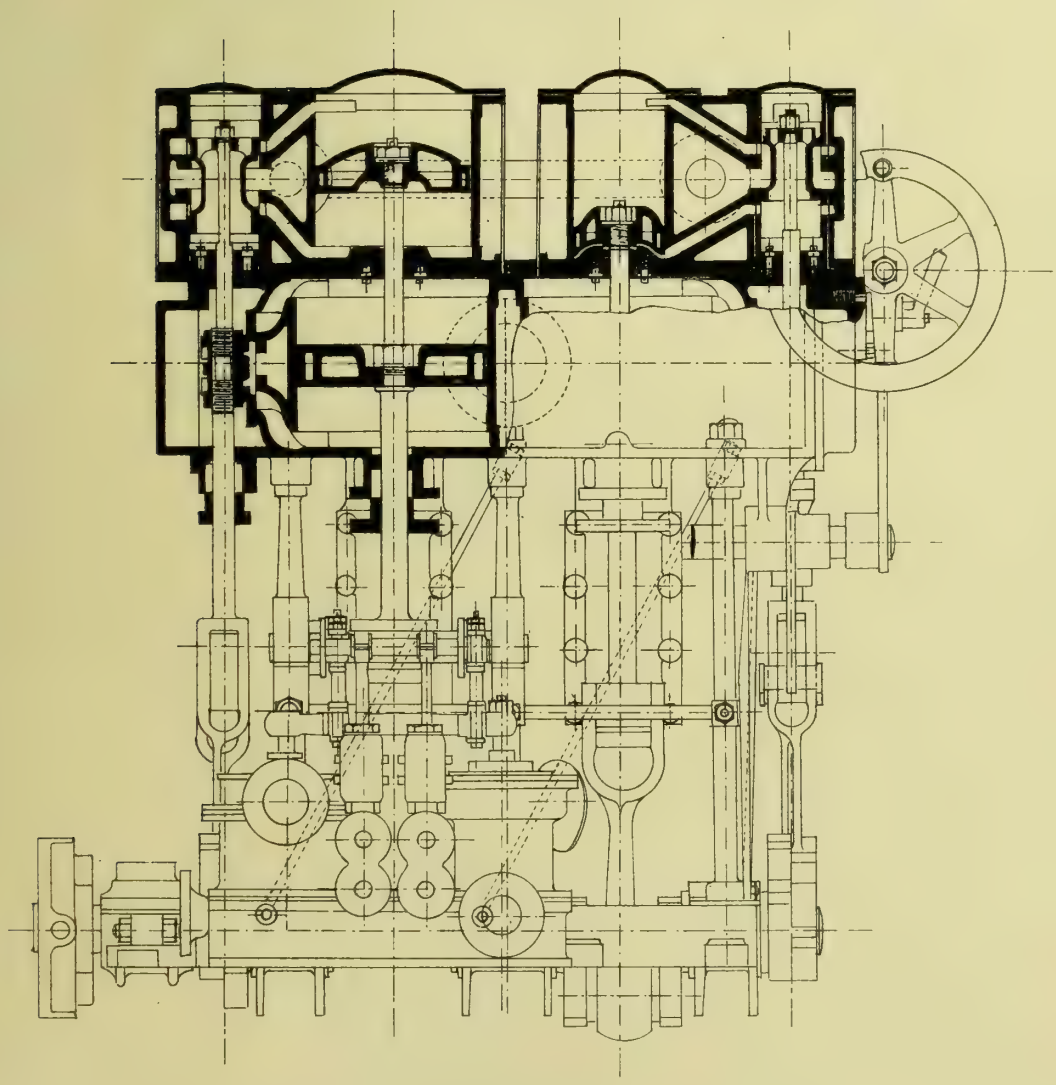


FIG. 6

To Illustrate Mr. A. Spyer's Paper on the Machinery of Small Steam Boats for Ships of War.

Triple Expansion Launch Engine.

FIG. I.

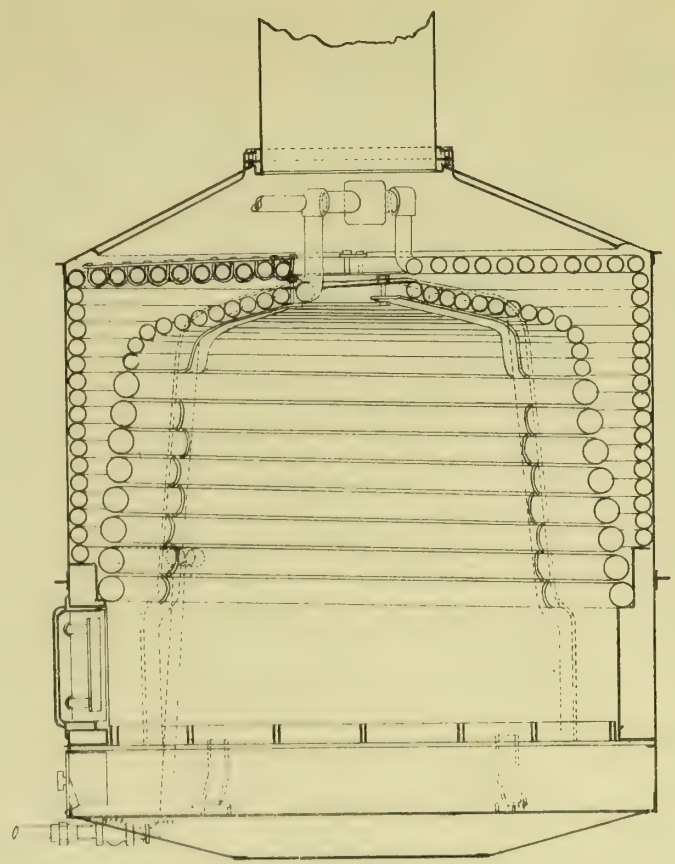


Scale 1" = One foot.

To Illustrate Mr. A. Spyer's Paper on the Machinery of Small Steam Boats for Ships of War.

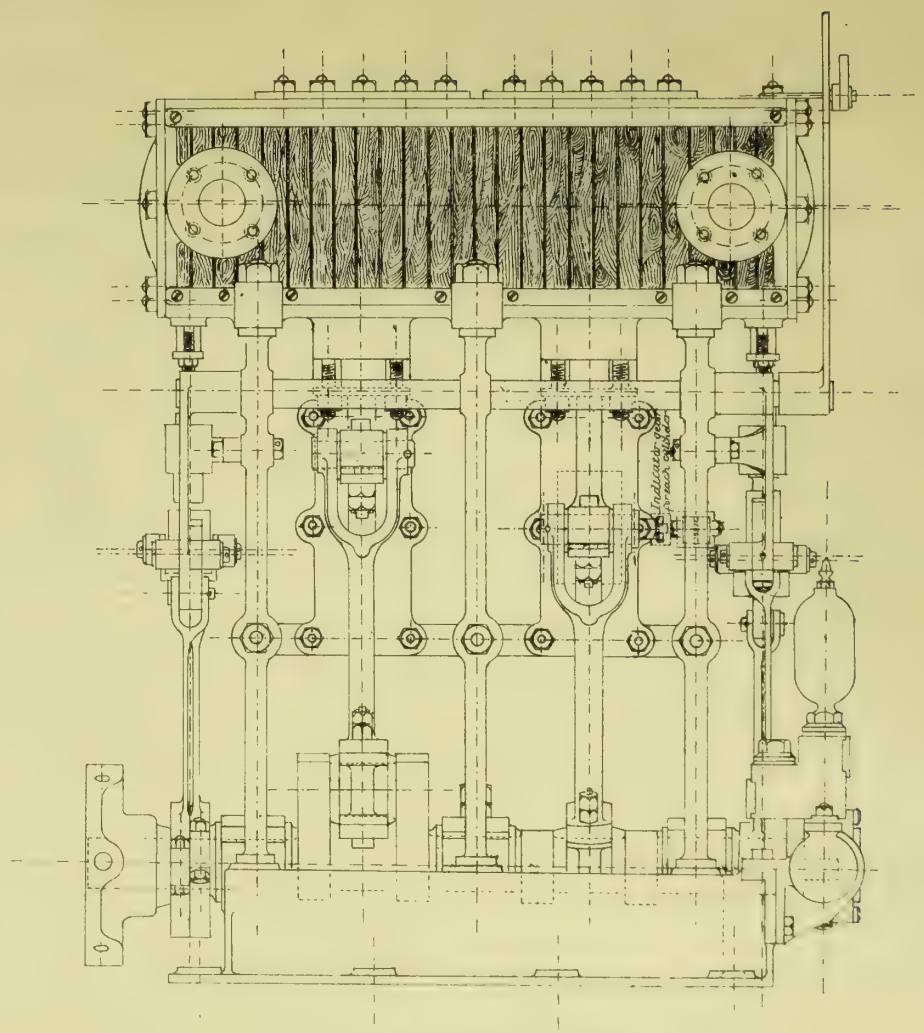
HERRESHOFF COIL BOILER

FIG. 5.



SIMPLE ENGINES FOR 37 FT PINNACE

FIG. 2.

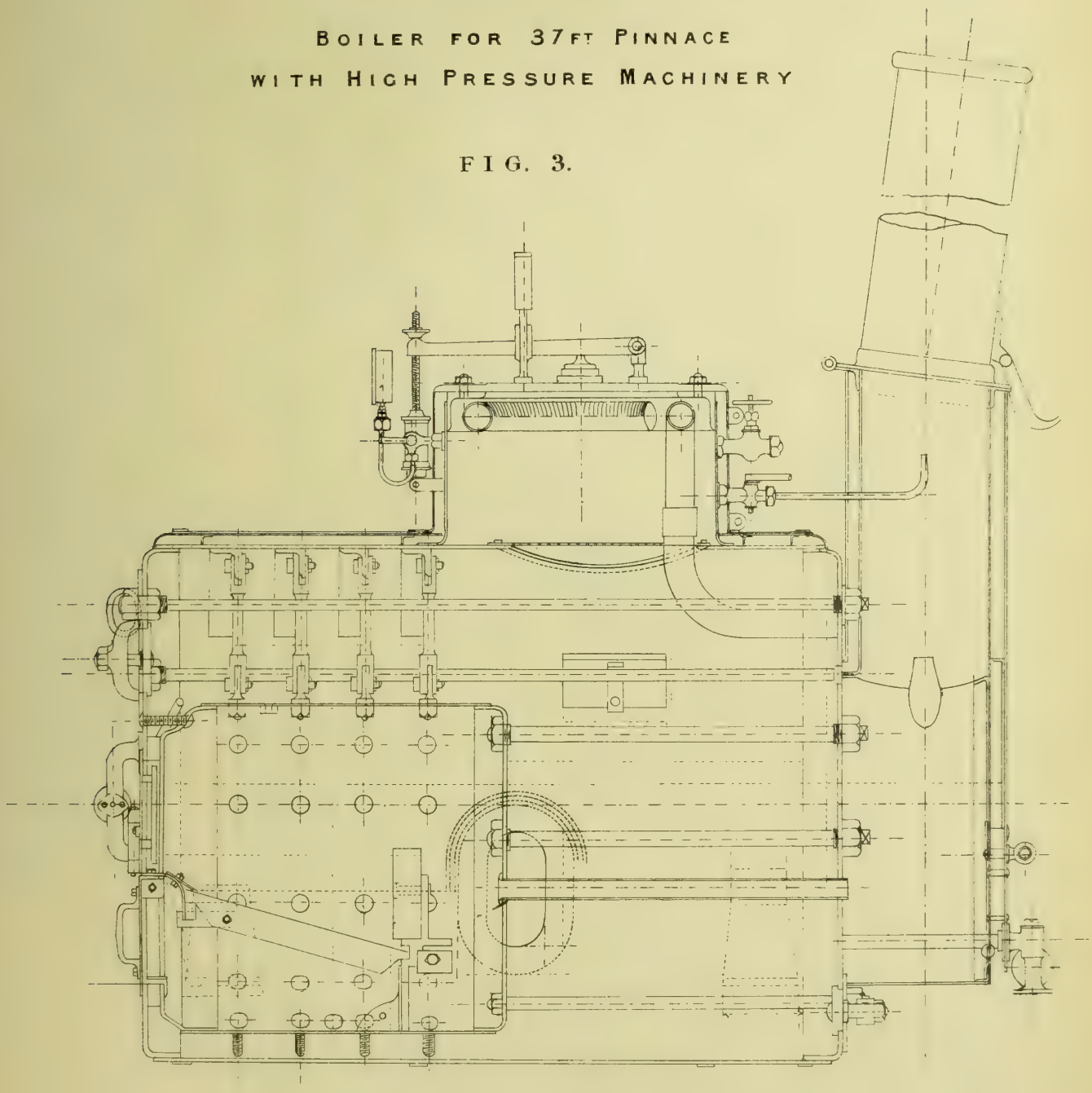


Scale 1½" - One Foot.

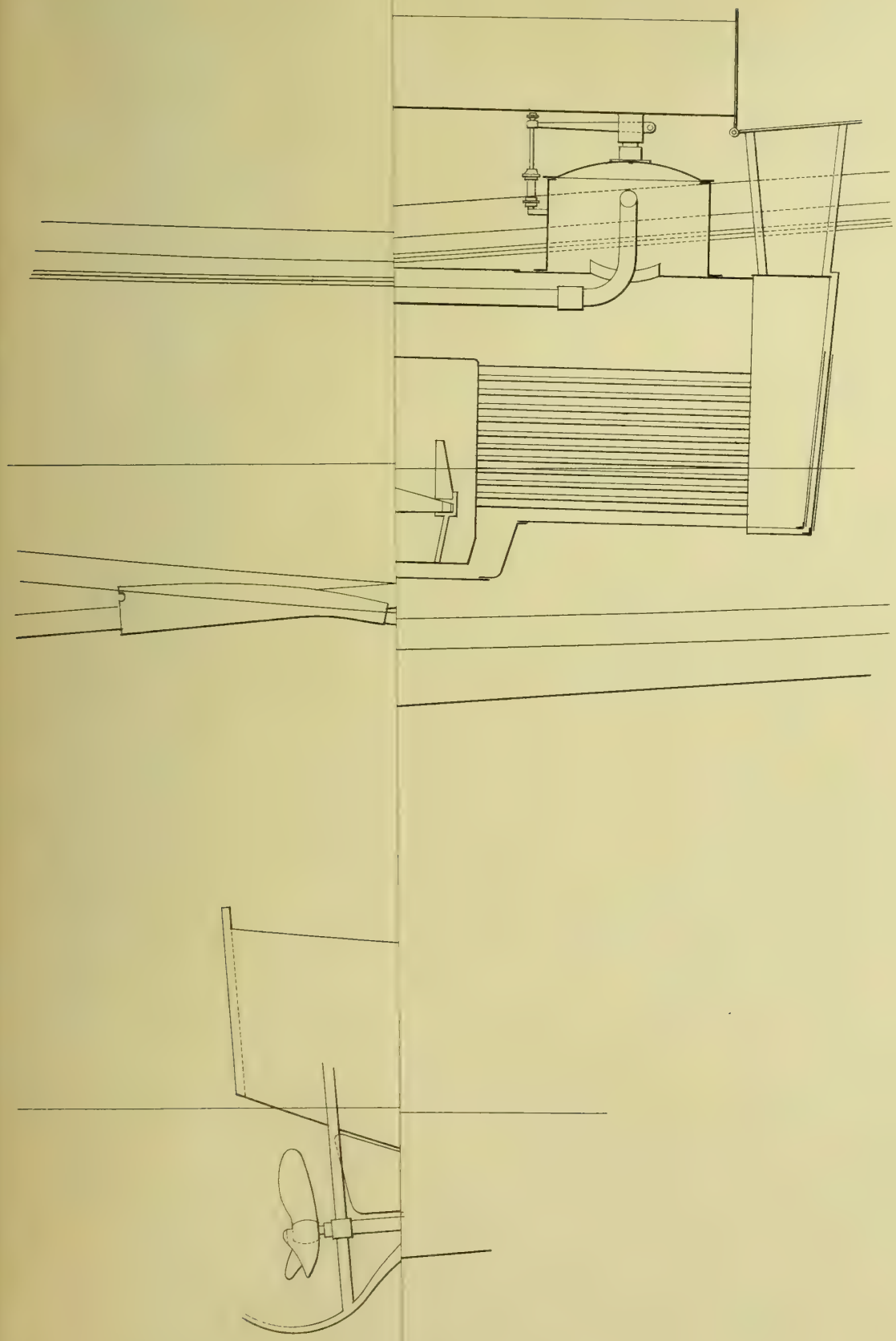
To Illustrate Mr. A. Spyer's Paper on the Machinery of Small Steam Boats for Ships of War.

BOILER FOR 37FT PINNACE
WITH HIGH PRESSURE MACHINERY

FIG. 3.



Scale 1'-One Foot.

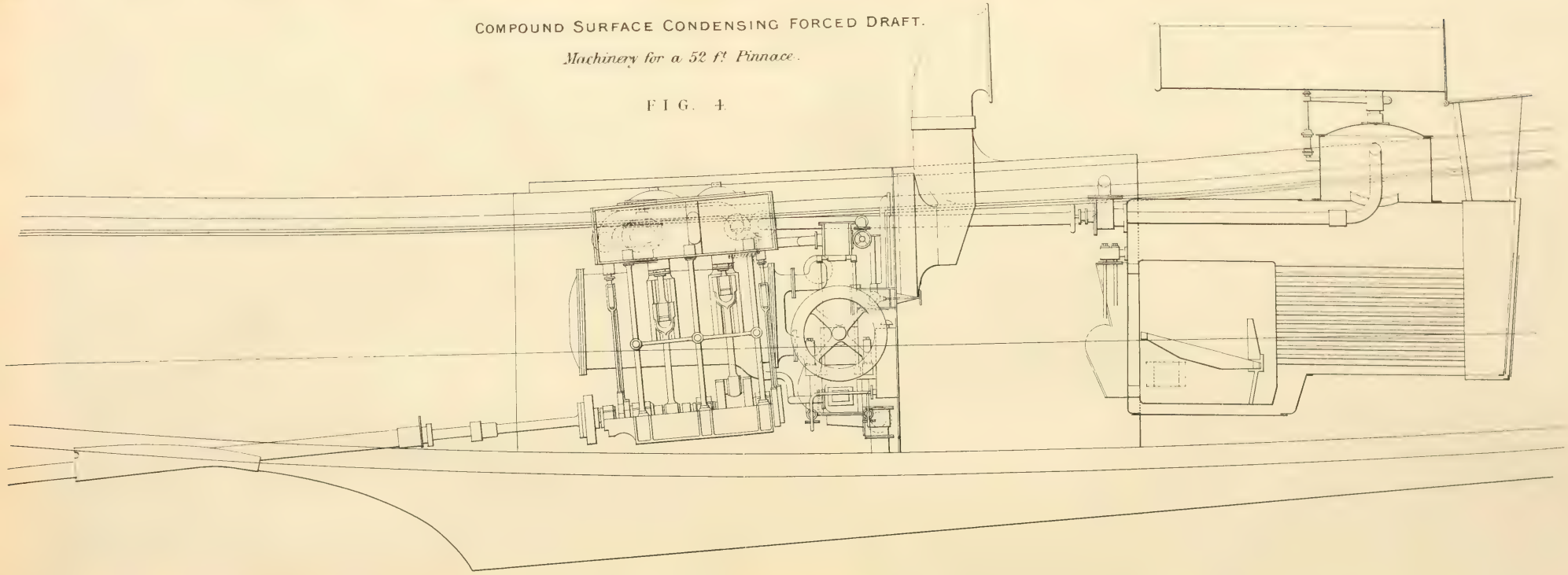


To Illustrate Mr. A. Spyer's Paper on the Machinery of Small Steam Boats for Ships of War.

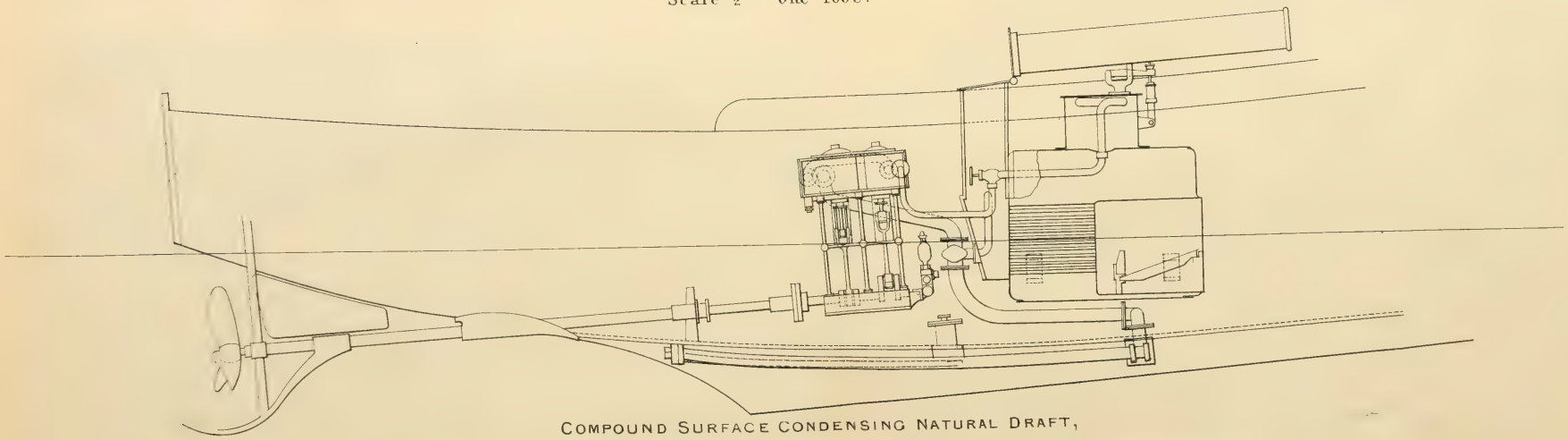
COMPOUND SURFACE CONDENSING FORCED DRAFT.

Machinery for a 52 ft. Pinnace.

FIG. 4.



Scale $\frac{1}{2}''$ = One foot.



COMPOUND SURFACE CONDENSING NATURAL DRAFT,

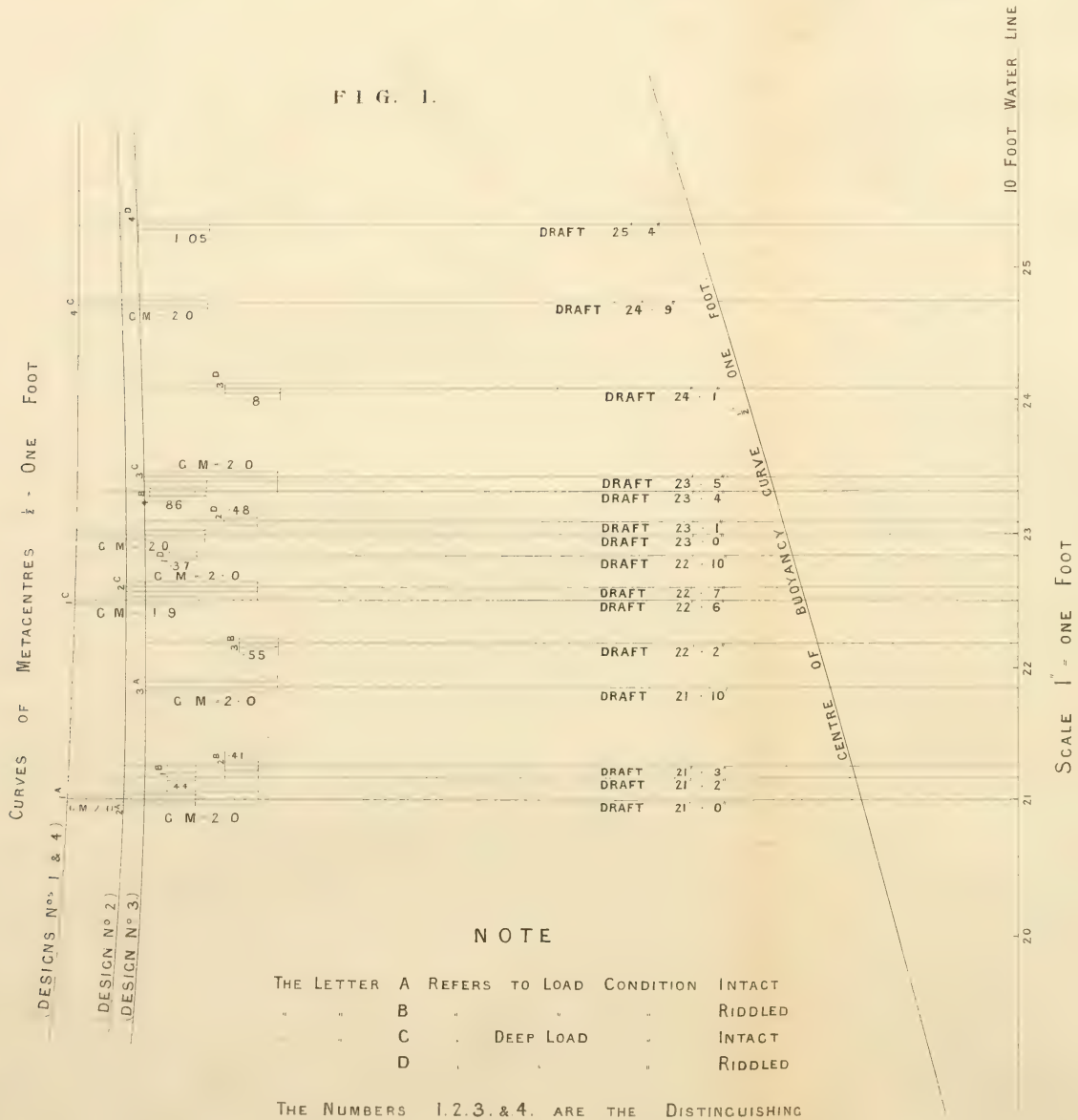
Machinery for 28 ft. Cutter.

Scale $\frac{1}{2}''$ = One foot.

FIG. 6.

To Illustrate Mr. J. H. Biles' Paper on Comparative Effects of side and internal Armoured Protection upon the other Elements of Design of Cruisers.

FIG. 1.



NOTE

THE LETTER A REFERS TO LOAD CONDITION INTACT
" " B " " " RIDDLED
" " C " DEEP LOAD " INTACT
" " D " " " RIDDLED

THE NUMBERS 1.2.3.&4. ARE THE DISTINGUISHING NUMBERS OF THE DESIGNS.

BELTED CRUISER

ARMOURED DECK

SCALE 1/32" - ONE FOOT

NOTE IN CONDITIONS B. & D. SHADED PARTS ARE RIDDLED

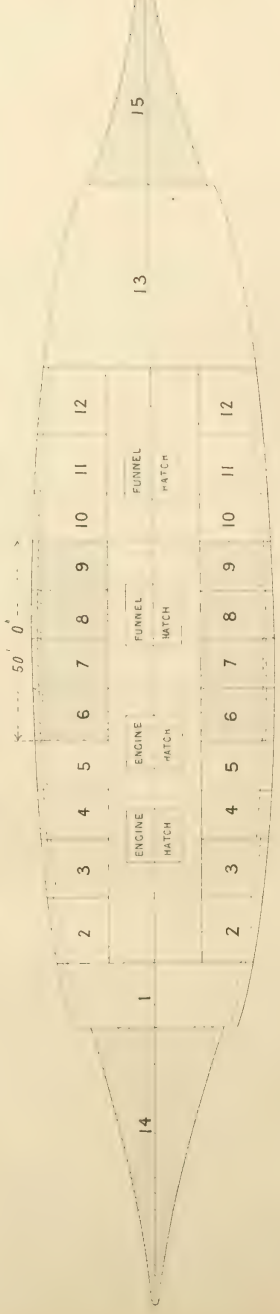
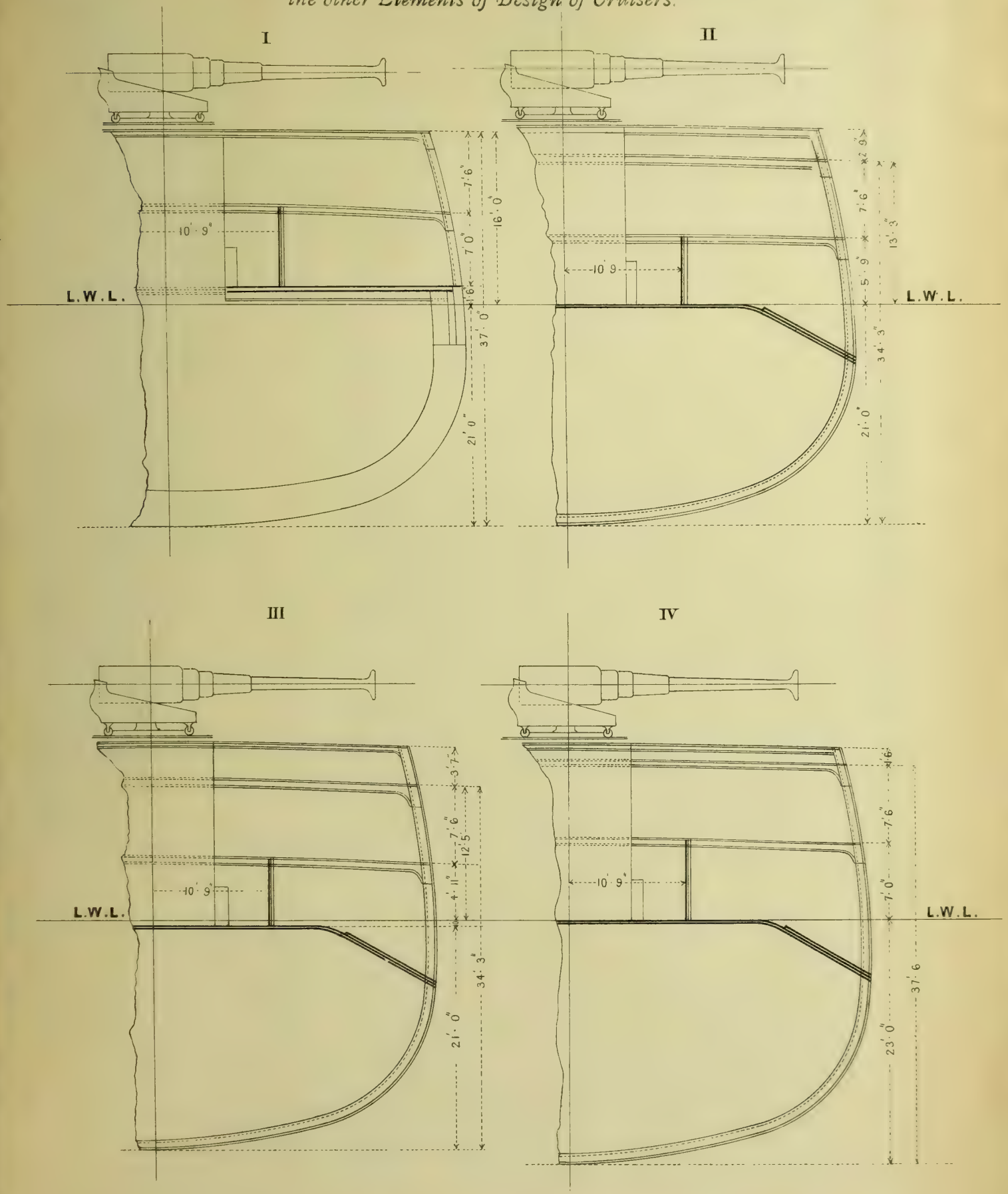


FIG. 2.

To Illustrate Mr. J. H. Biles' Paper on Comparative Effects of side and internal Armoured Protection upon the other Elements of Design of Cruisers.



I	300 × 36' × 37 – 0'	III	300' × 53'-0" × 34'-3".
II	300' × 53'-9" × 34'-3"	IV	316' × 56'-0 × 37'-6".

To Illustrate Professor P. Jenkin's Paper on the Shifting of Cargoes.

FIG. 1.

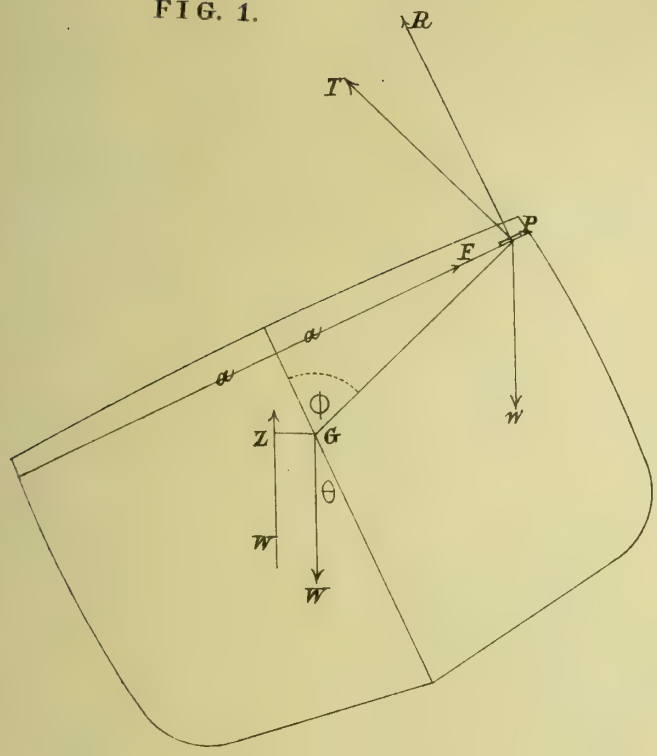


FIG. 2.

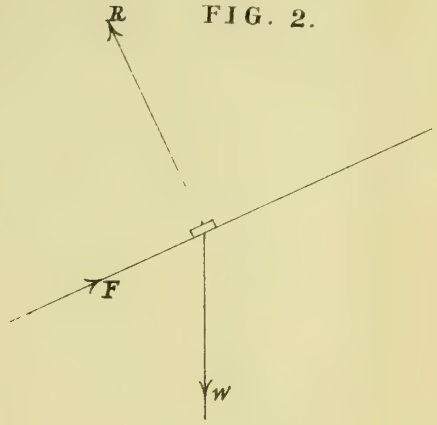


FIG. 3.

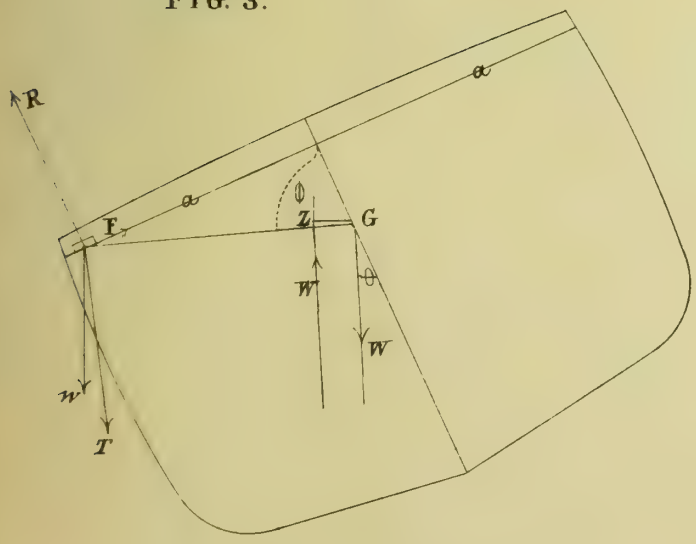
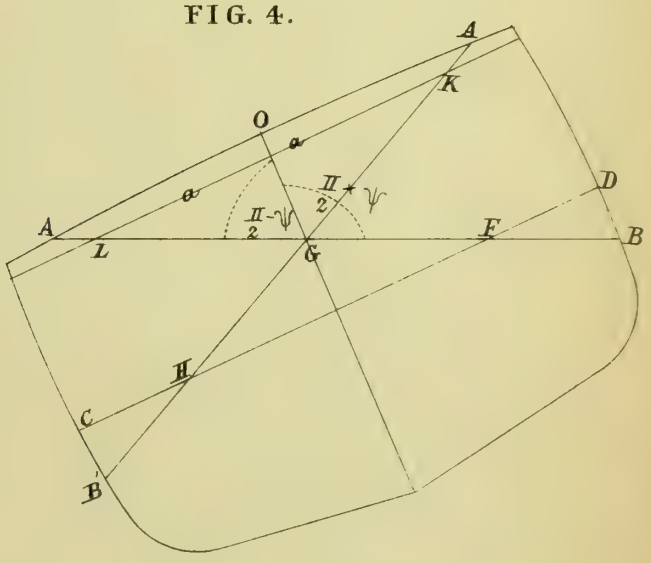
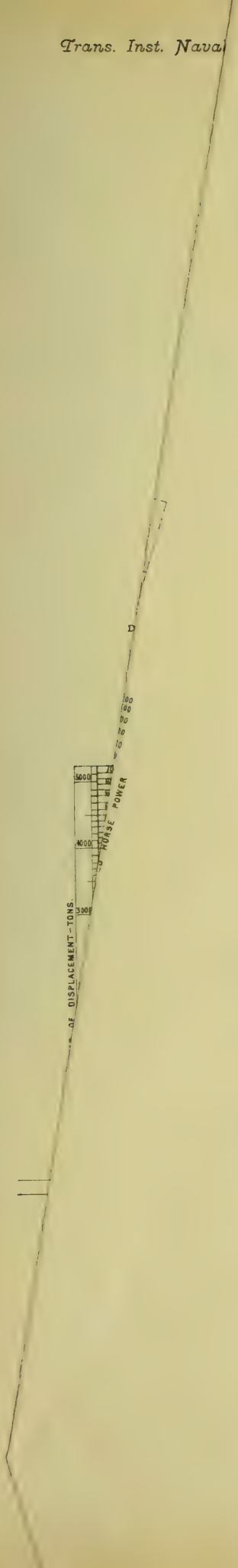


FIG. 4.




5000
4000
3000
HORSE POWER
DISPLACEMENT - TONS.

To Illustrate Mr. A. Denny's Paper on the Practical Application of Stability Calculations.

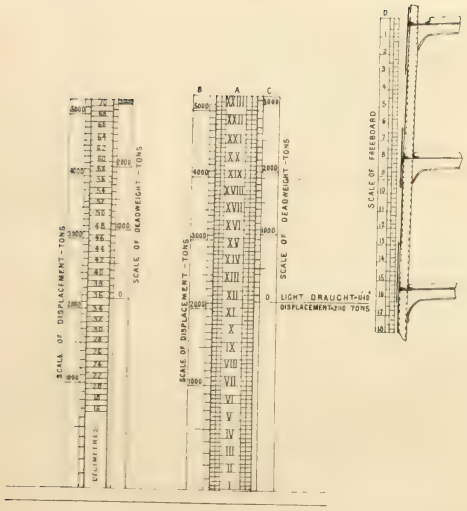


FIG. 1.

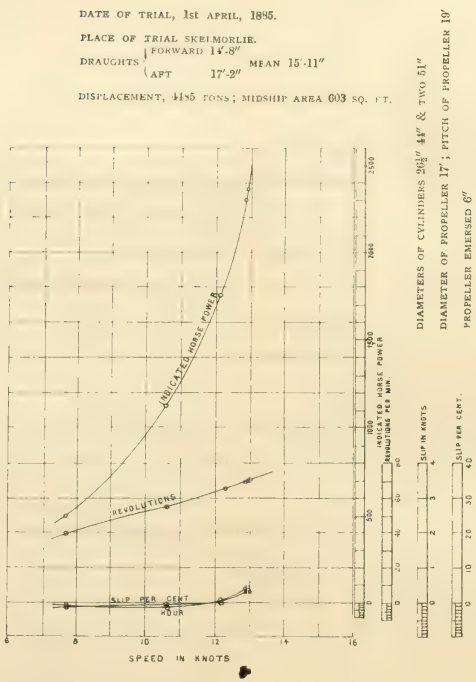


FIG. 2.

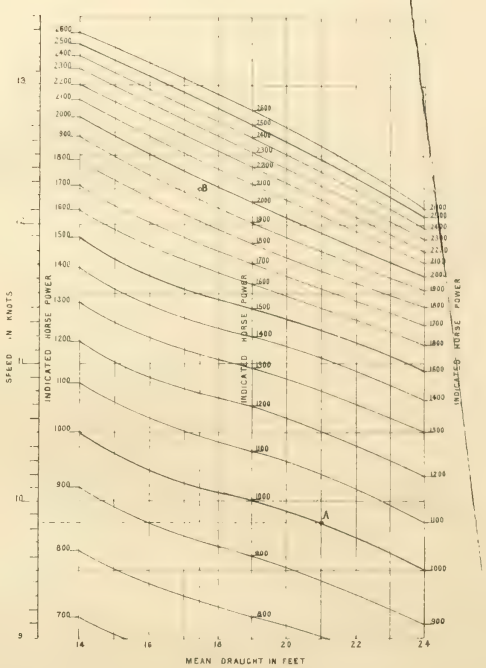


FIG. 3.

To Illustrate Mr. A. Denny's Paper on the Practical Application of Stability Calculations.

FIG. 4. S. S. "C."

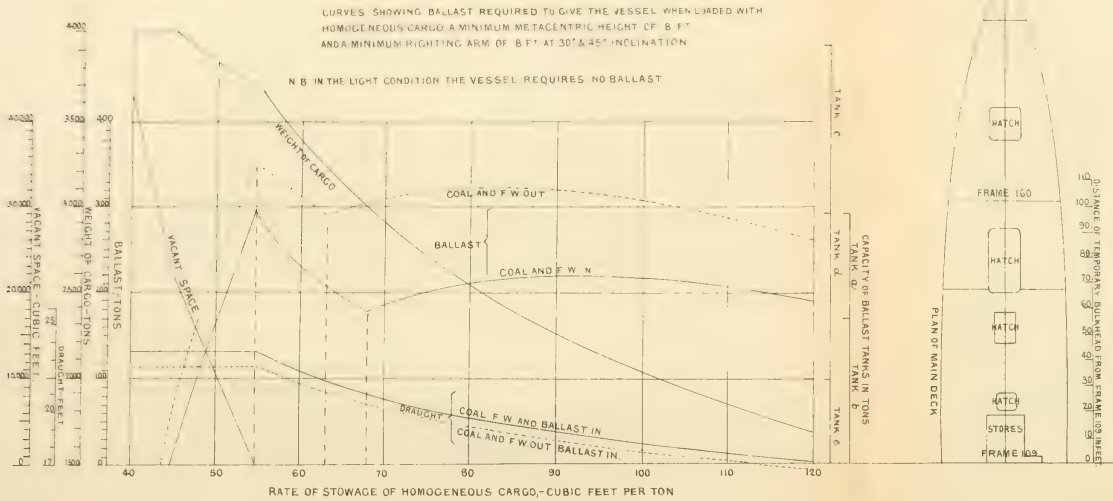


FIG. 6. S. S. "B."

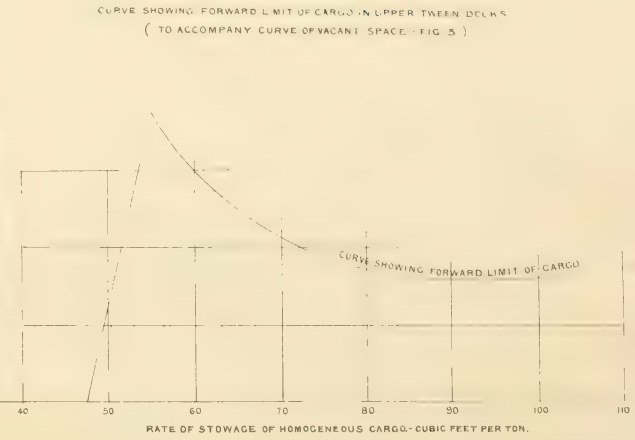


FIG. 5. S. S. "B"

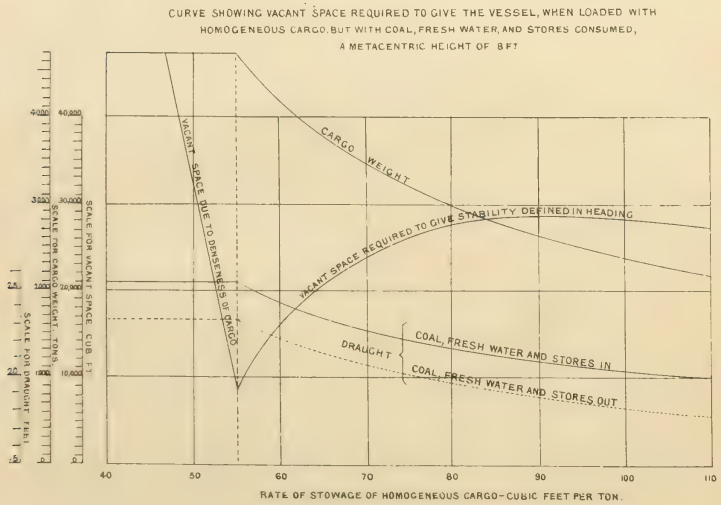
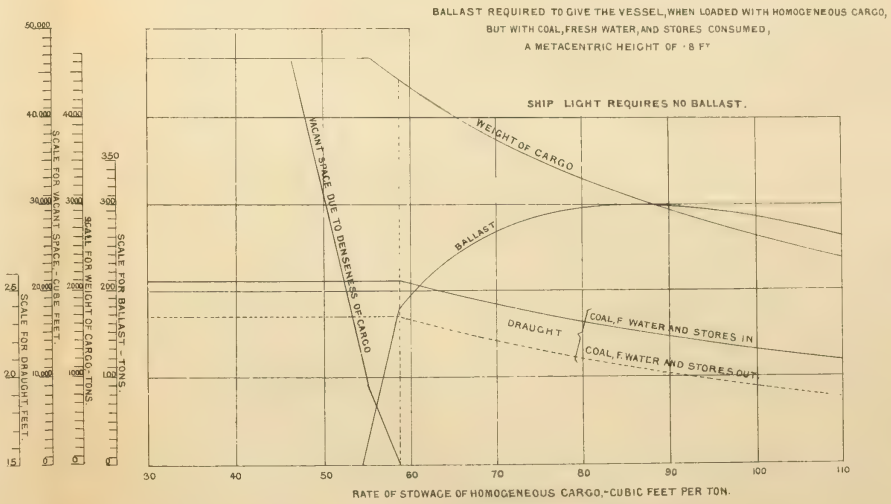
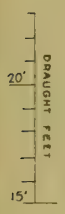


FIG. 7. S. S. "B."





TANCE FROM 1

To Illustrate Mr. A. Denny's Paper on the Practical Application of Stability Calculations.

FIG. 8. S. S. "A".

TRIM OF VESSEL WHEN LOADED WITH HOMOGENEOUS CARGOES OF VARYING DENSITIES NO BALLAST IN

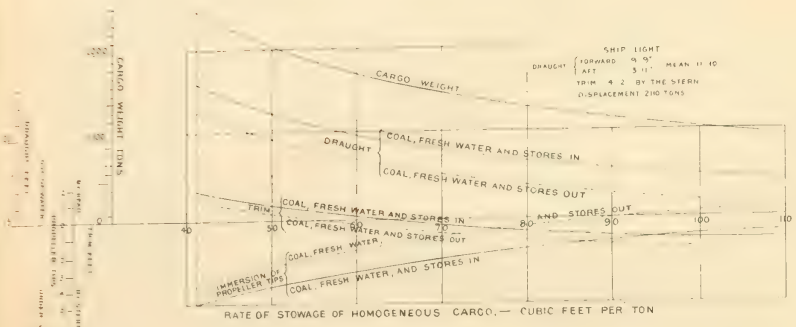
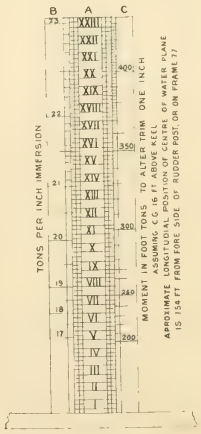


FIG. 9.

S. S. "A"

SCALES OF TONS PER INCH, AND MOMENT TO ALTER TRIM



ARRANGEMENT OF PENDULUM FOR THE INCLINING DIAGRAMS

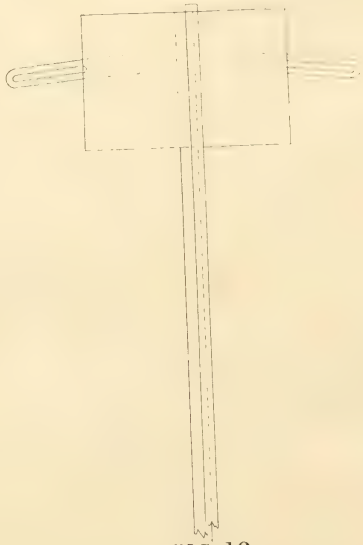


FIG. 10A.

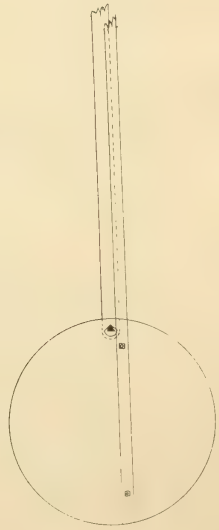
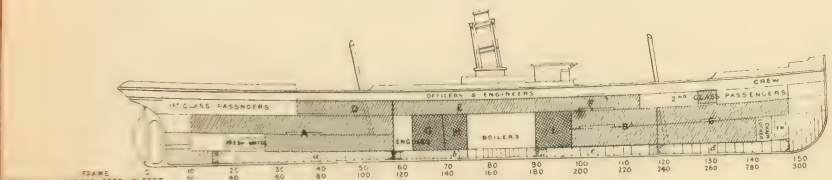


FIG. 10. S. S. "A"

PROFILE SHOWING THE DISTRIBUTION OF CARGO AND COAL



		CARGO IN CUB FT	CENTRE OF SPACE FROM RUDDER POST FT	CENTRE OF SPACE ABOVE TOP OF KEEL FT
LARGE SPACE	A	3 490	77 4	13 4
	B	22070	216 0	12 2
	C	29600	258	14 3
	D	3390	95 5	23 7
	E	3680	145 6	23 3
	F	1875	204 2	24 2
TOTAL CARGO		62410	165 0	16 2
SHIP LIGHT		2110	152 8	16 8
FRESH WATER	FORWARD	1880 GALLONS		
	AFT	6228		
	TOTAL	8108		

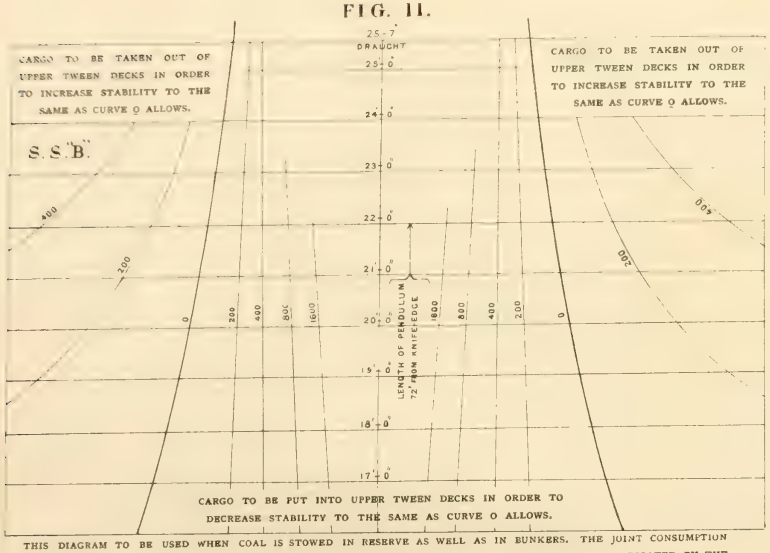
		CAPACITY IN TONS 44 CUB FT = 1 TON	CENTRE OF SPACE FROM RUDDER POST FT	CENTRE OF SPACE ABOVE TOP OF KEEL FT
COAL IN BUNKERS	PORT	401	130 0	11 6
	STARBOARD	181	133 0	11 6
		94	143 8	12 7
		208	188 0	11 8
TOTAL COAL		361	167 0	12 0
35 CUBIC FT = 1 TON				
BOTTOM WATER BALLAST TANKS		97	81 8	2 3
		142	147 0	2 0
		106	205 6	2 0
		40	256 9	2 2
TOTAL WATER BALLAST		385	158 1	2 1

CARGO SPACE

COAL BUNKERS

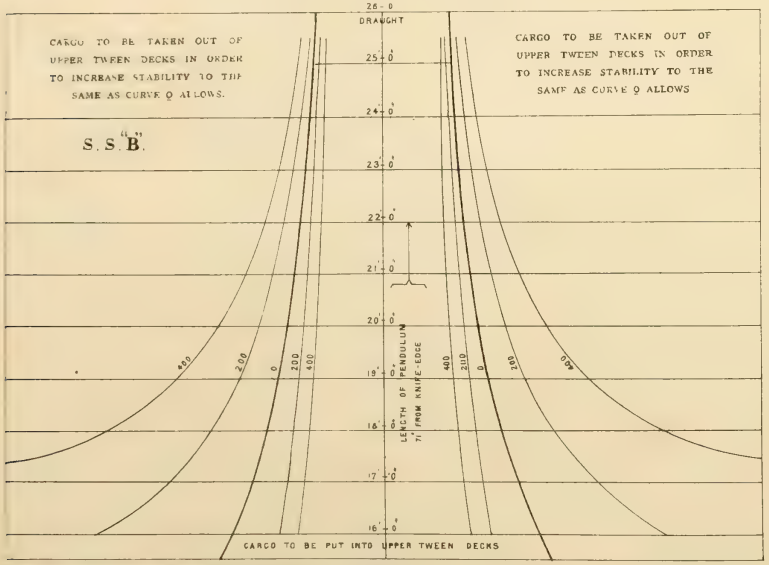
To Illustrate Mr. A. Denny's Paper on the Practical Application of Stability Calculations.

FIG. 11.



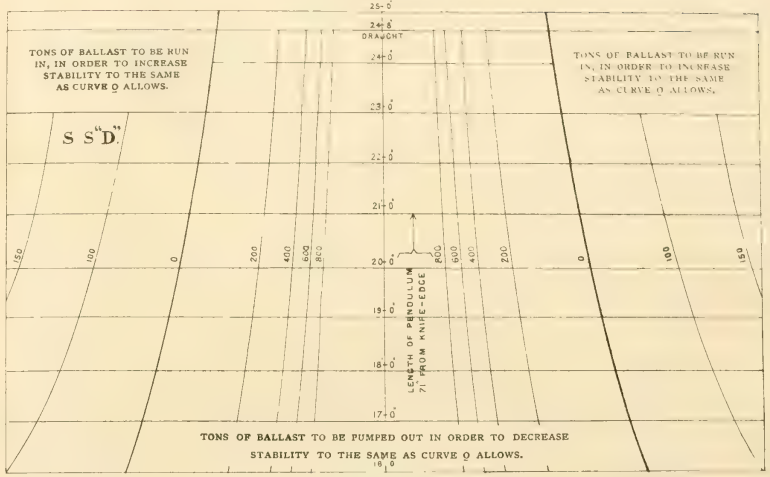
THIS DIAGRAM TO BE USED WHEN COAL IS STOWED IN RESERVE AS WELL AS IN BUNKERS. THE JOINT CONSUMPTION OF COAL AND DRINKING WATER CAUSES AN INCREASE OF STABILITY. THE STABILITY THEREFORE INDICATED BY THE DIAGRAM IS THE VERY LEAST WITH WHICH IT IS RECOMMENDED THE SHIP SHOULD EVER BE WORKED.
INCLINING MOMENT 14×16=224 EACH SIDE OF UPRIGHT.

FIG. 12.



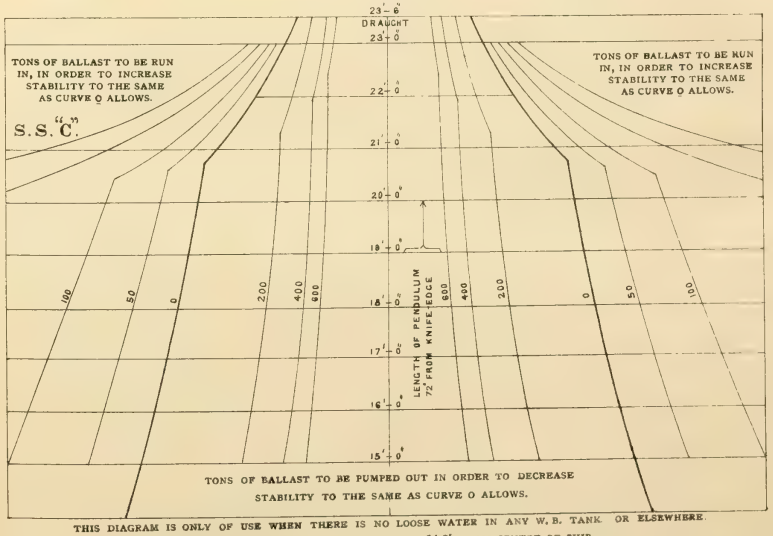
THIS DIAGRAM TO BE USED WHEN COAL IS STOWED IN BUNKERS ONLY, NOT IN THE RESERVE. THE CONSUMPTION OF BUNKER COAL AND DRINKING WATER CAUSES DECREASE OF STABILITY. THE STABILITY THEREFORE INDICATED BY THE DIAGRAM IS SUFFICIENT TO ALLOW FOR THIS DECREASE, AND LEAVE THE SHIP RIGHT AFTER THE COAL AND WATER ARE USED.
INCLINING MOMENT 14×16=224 EACH SIDE OF UPRIGHT.

FIG. 13.



THIS DIAGRAM IS ONLY OF USE WHEN THERE IS NO LOOSE WATER IN ANY W. B. TANK OR ELSEWHERE.
IT IS CALCULATED FOR 14 TONS PLACED 17' FROM THE CENTRE OF SHIP,
GIVING AN INCLINING MOMENT 238 (=14×17) EACH SIDE OF UPRIGHT.

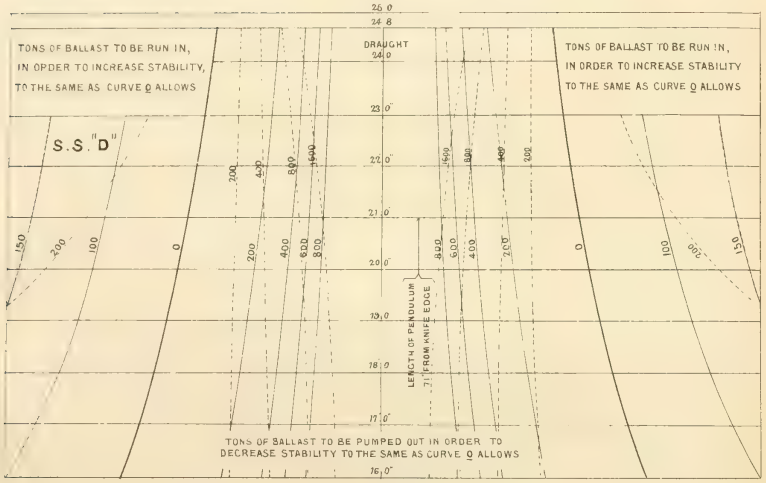
FIG. 14.



THIS DIAGRAM IS ONLY OF USE WHEN THERE IS NO LOOSE WATER IN ANY W. B. TANK OR ELSEWHERE.
IT IS CALCULATED FOR 12 TONS PLACED 14·8' FROM CENTRE OF SHIP,
GIVING AN INCLINING MOMENT 177·6 (=12×14·8) EACH SIDE OF UPRIGHT.

To Illustrate Mr. A. Denny's Paper on the Practical Application of Stability Calculations.

FIG. 15.



INCLINING MOMENT 14 × 17 · 238 EACH SIDE OF UPRIGHT
——— WATER BALLAST
------- CARGO IN TWEEN-DECKS.

FIG. 16.

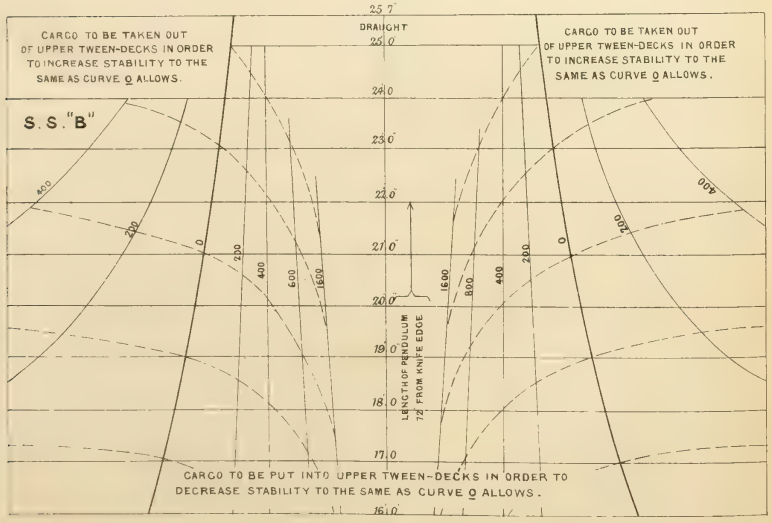


FIG. 17.

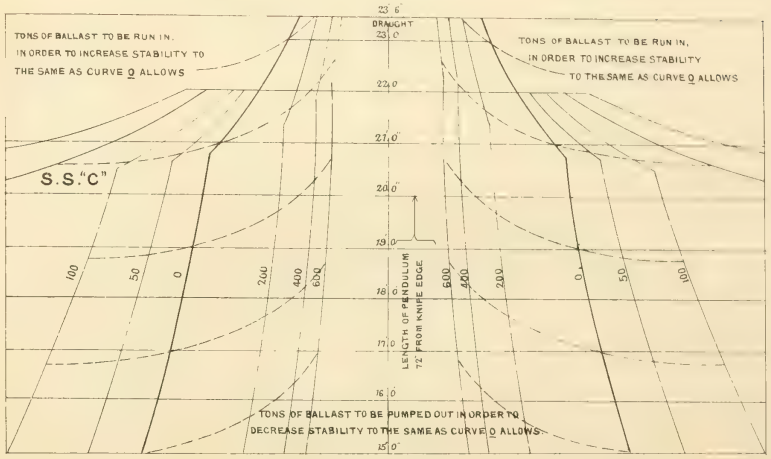
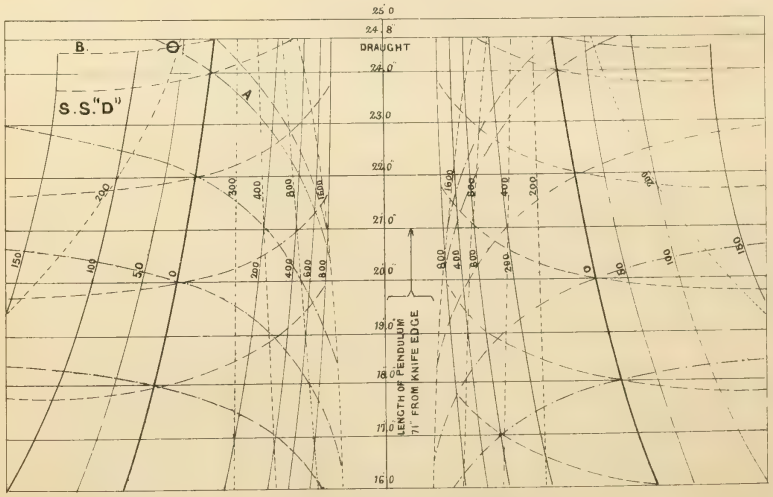
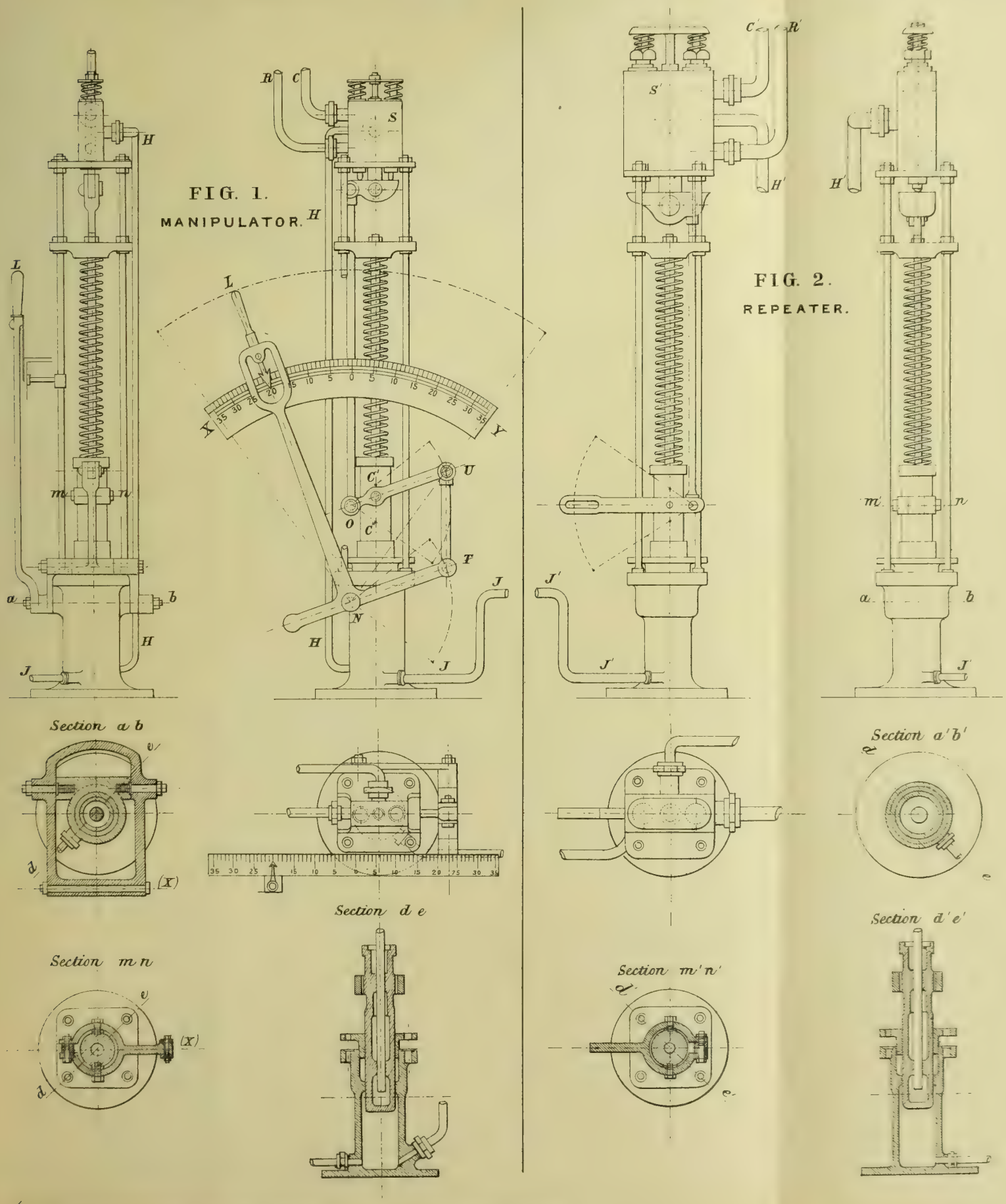


FIG. 18.



WATER BALLAST
CARGO IN TWEEN-DECKS.

To Illustrate Mons. E. Widmann's Paper on the Principle of an Hydraulic Apparatus for transmitting Signals and Power, and controlling all sorts of distant Mechanism.



(X) The manipulating levers are supposed to be in their mean positions.

er, and controlling all Sorts of distant Mechanism.

IG. 2. Vertical section along the axis.

FIG. 3. Section e.f.

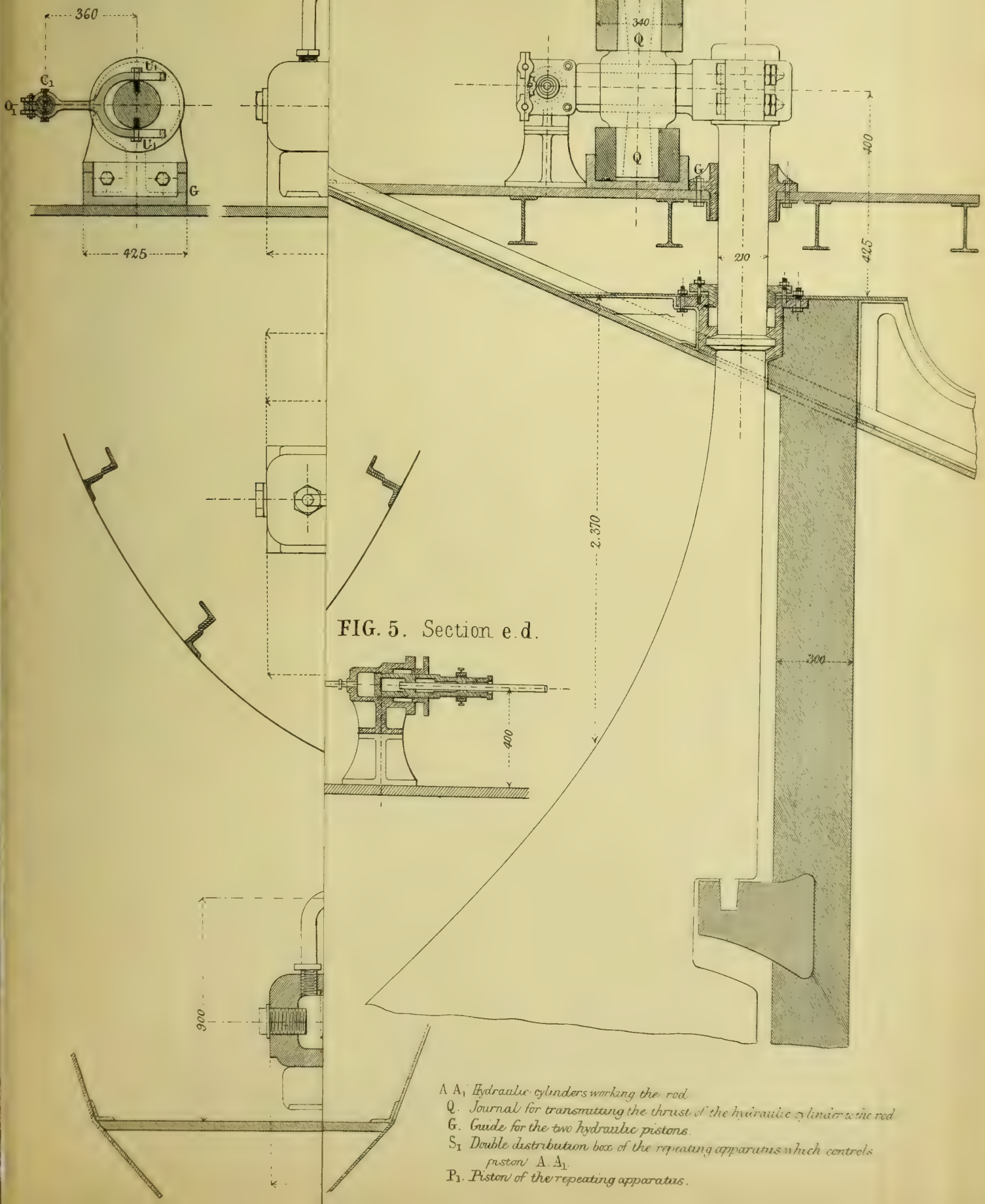


FIG. 5. Section e.d.

A A1 Hydraulic cylinders working the rod.
Q. Journal for transmitting the thrust of the hydraulic cylinder to the rod.
G. Guide for the two hydraulic pistons.
S1 Double distribution box of the repeating apparatus which controls piston A. A1.
P1. Piston of the repeating apparatus.

To Illustrate Mons. E. Widmann's Paper on the Principle of an Hydraulic Apparatus for transmitting Signals and Power, and controlling all Sorts of distant Mechanism.

Application to working a Rudder.

FIG. 1. Elevation

FIG. 2. Vertical section along the axis.

FIG. 3. Section e f.

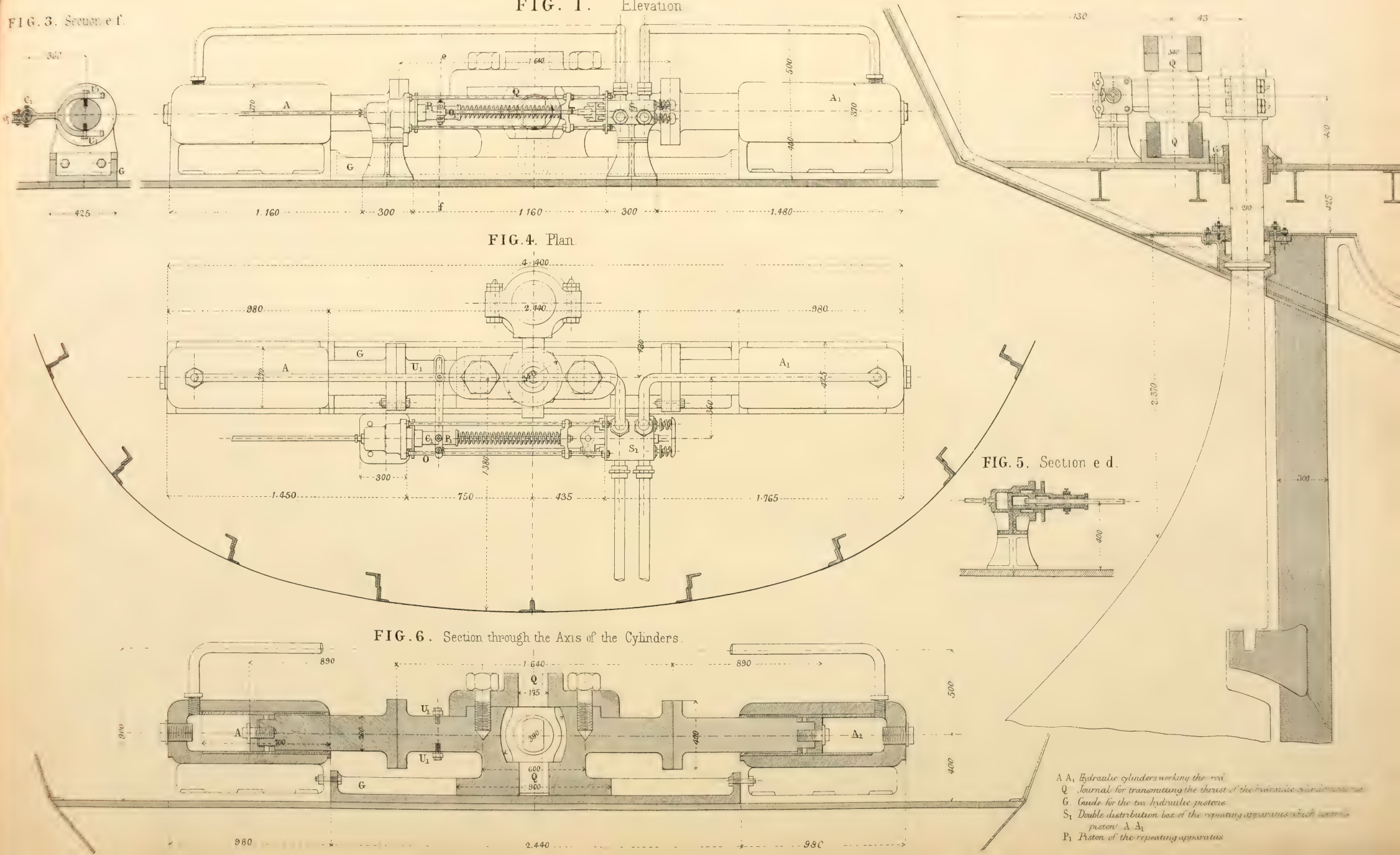


FIG. 4. Plan.

FIG. 5. Section e d.

FIG. 6. Section through the Axis of the Cylinders.

To Illustrate Mr. E. A. Linnington's Paper on some recent High-speed Twin Screws.

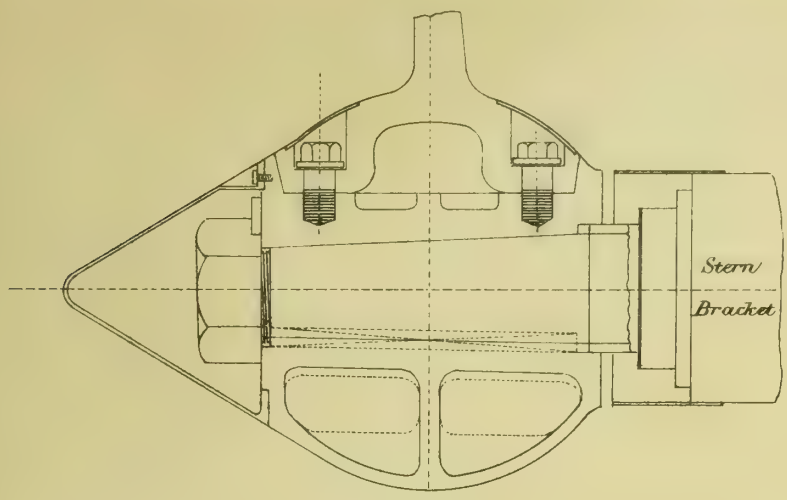


FIG. 1.

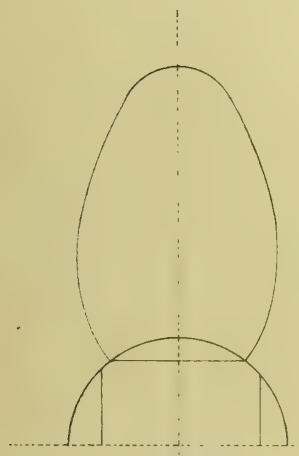


FIG. 2.

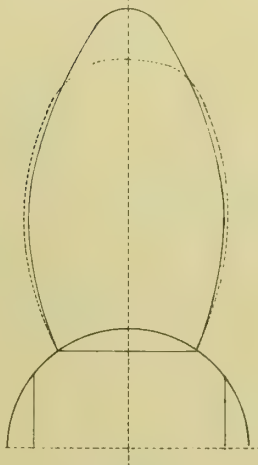


FIG. 3.

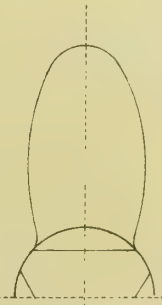
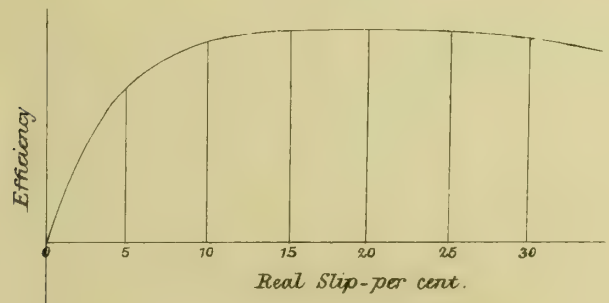


FIG. 4.



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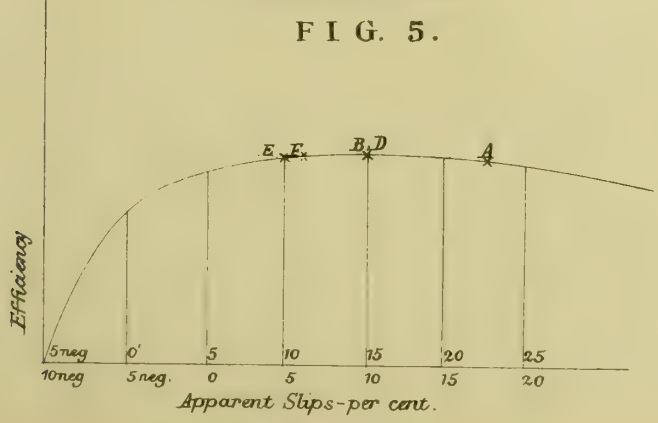


FIG. 6.

To Illustrate Professor R. H. Thurston's Paper on the Forms of Fish and of Ships

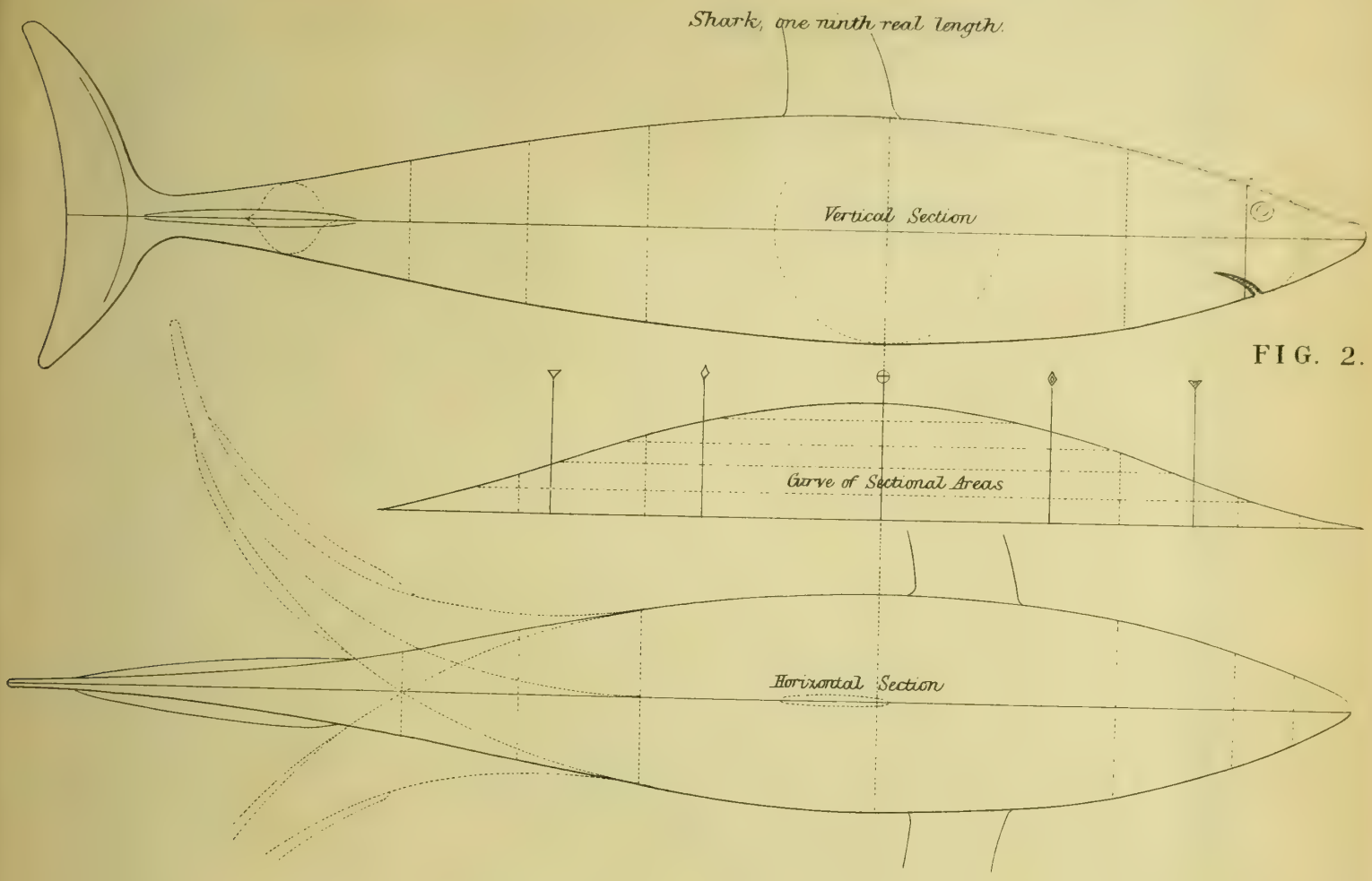
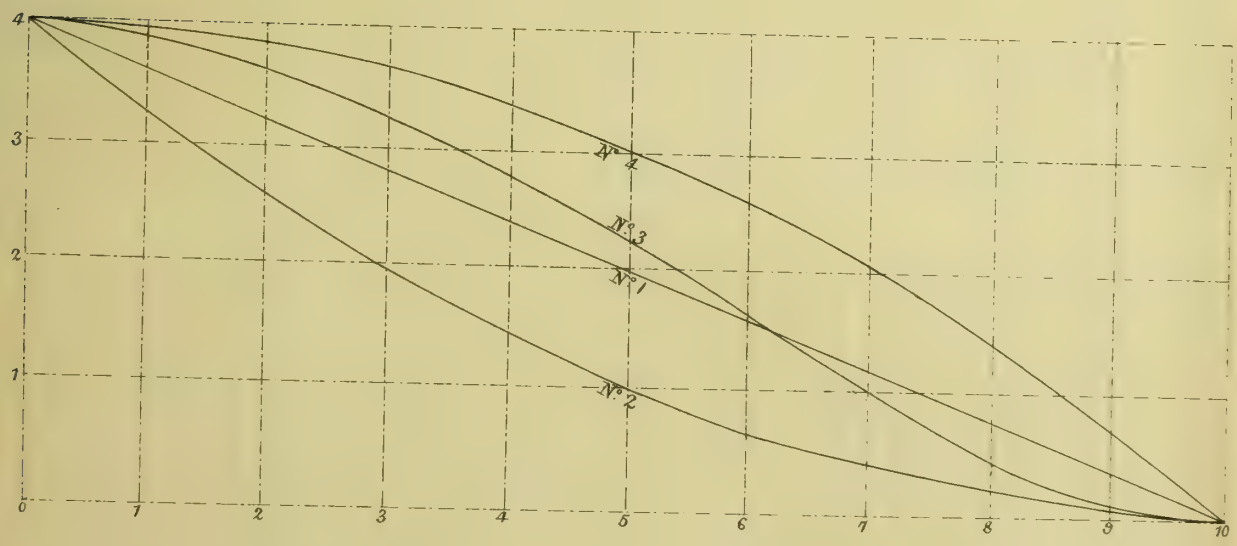


FIG. 2.

FIG. 1.



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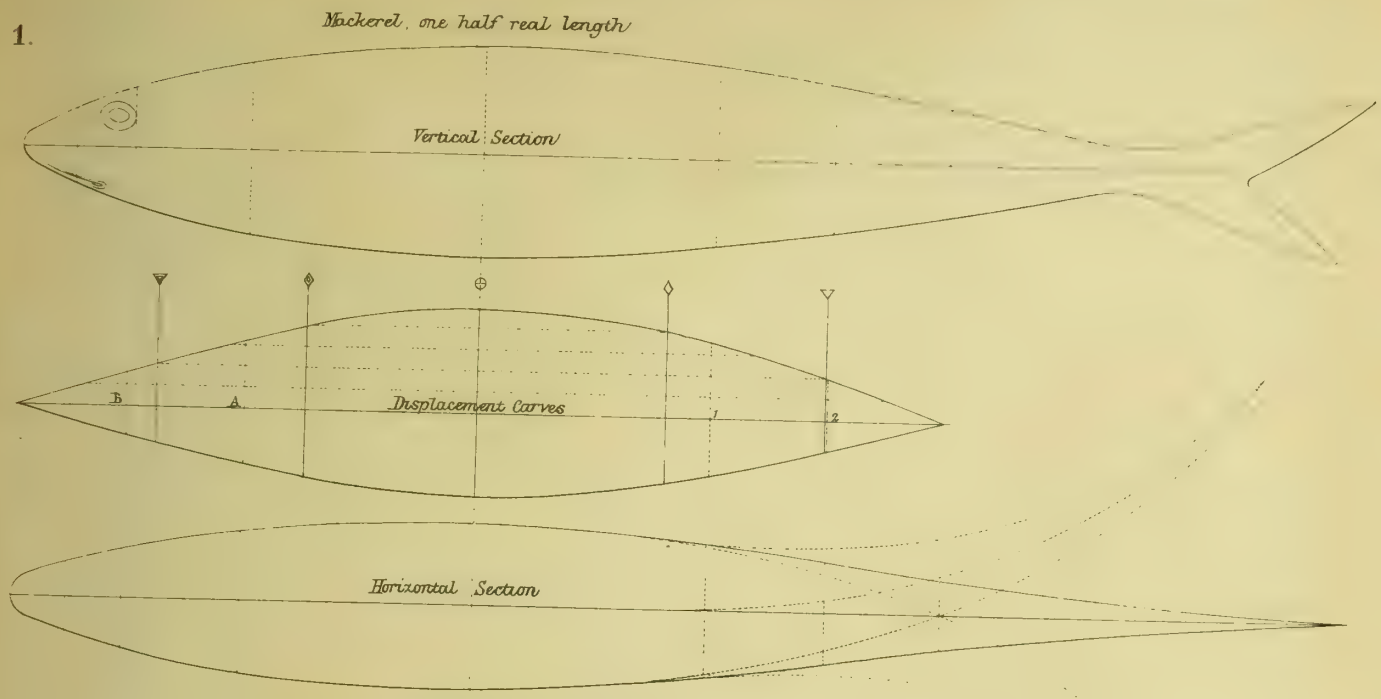
To Illustrate Professor R. H. Thurston's Paper on the Forms of Fish and of Ships.

FIG. 1.



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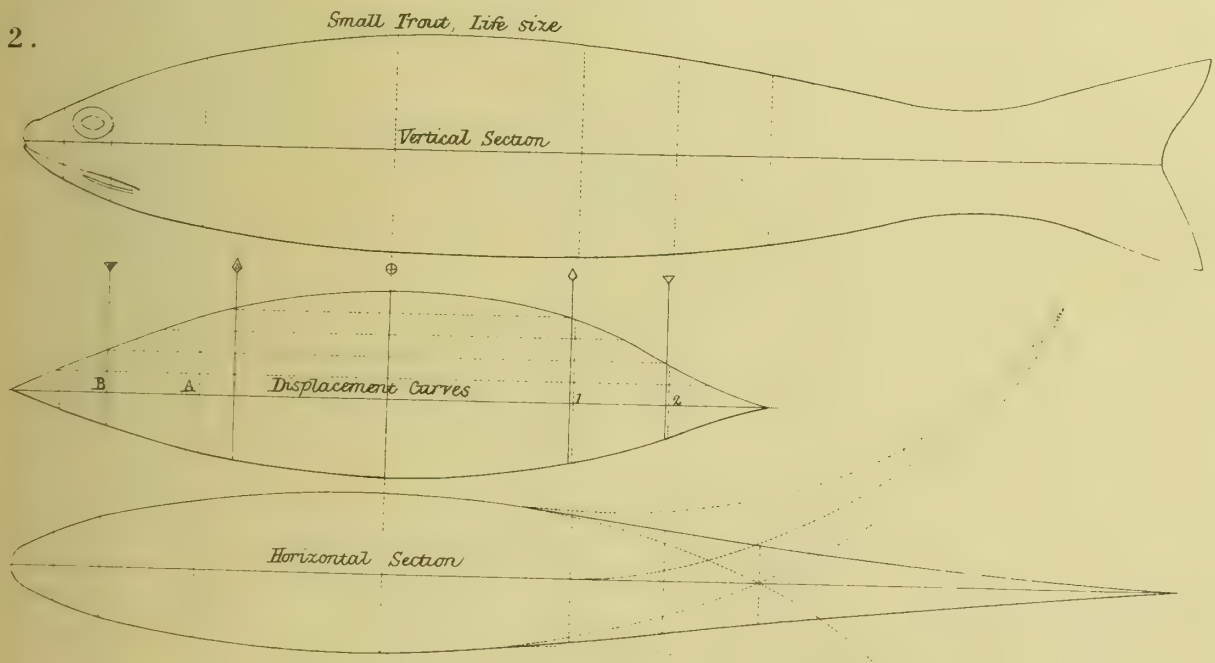
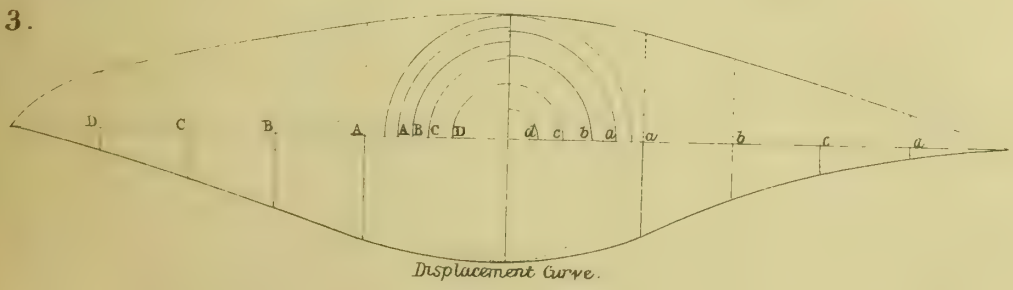
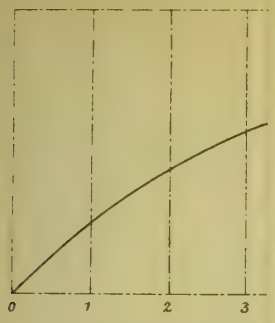


FIG. 3.

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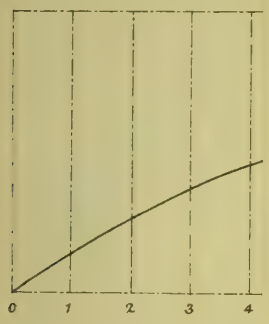
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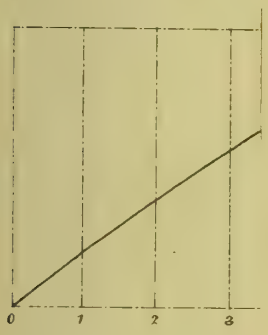
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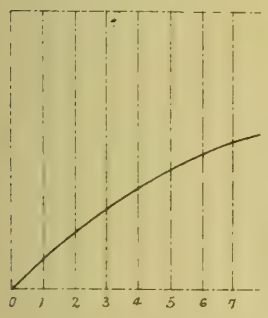
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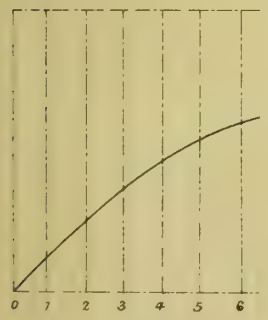
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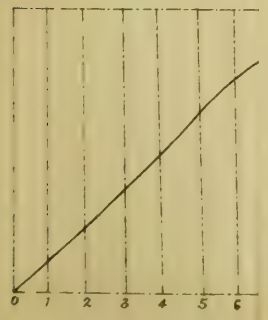
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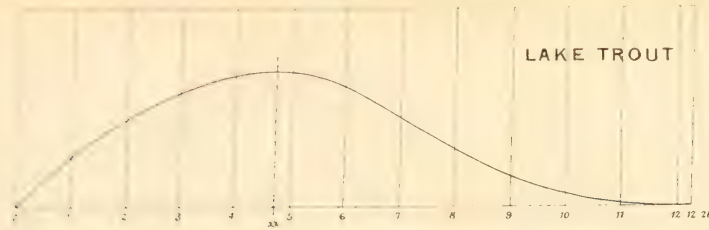
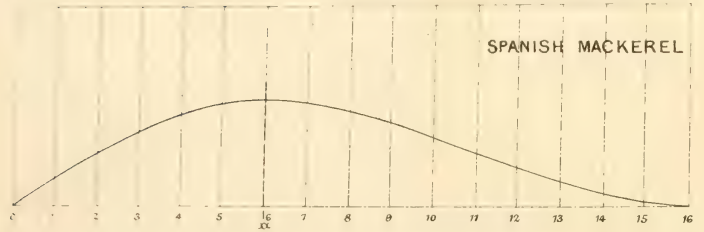
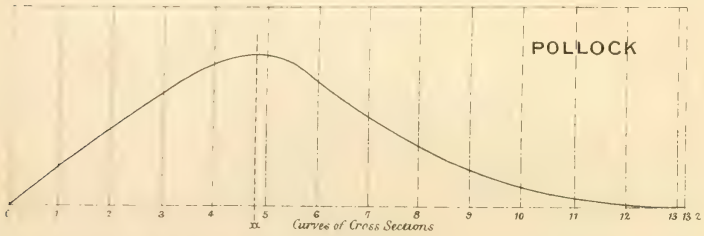
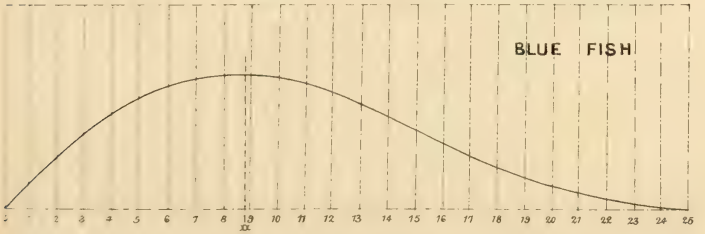
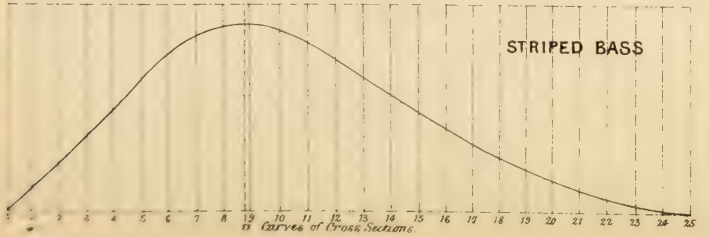

LAKE TROUT

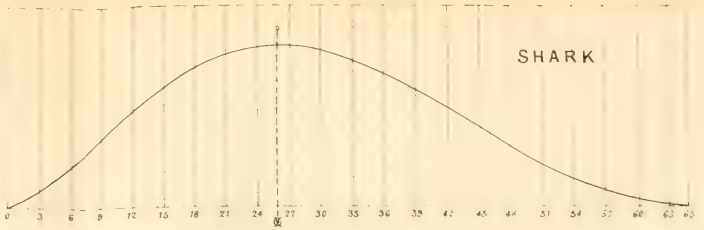

SPANISH MACKEREL

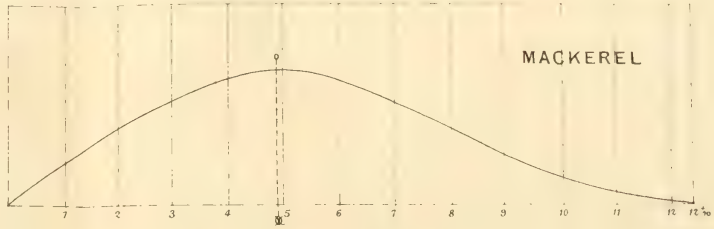

POLLOCK
Curves of Cross Sections

RESTIGOUCHE SALMON


BLUE FISH


STRIPED BASS
Curves of Cross Sections.


SHARK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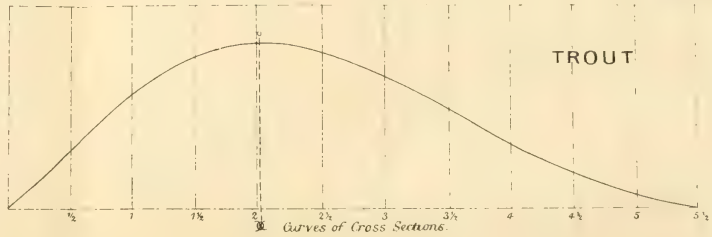

TROUT
Curves of Cross Sections.

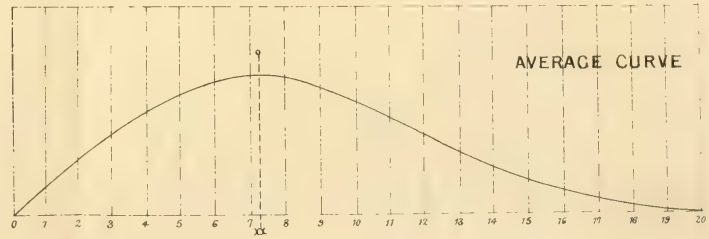
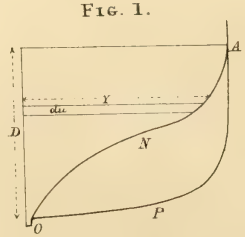

AVERAGE CURVE

FIG. 1.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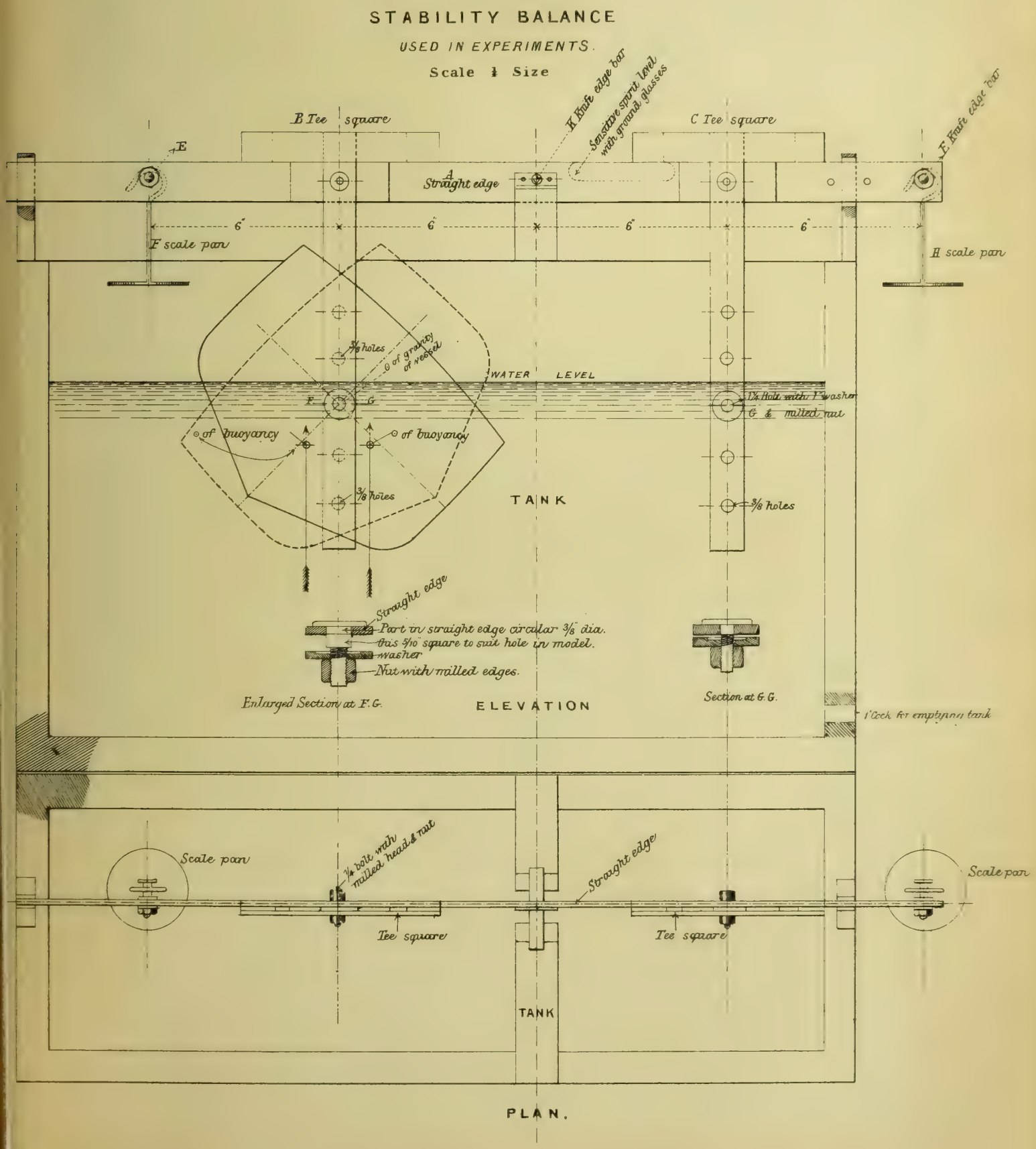
To Illustrate Mr. J. H. Heck's Paper on a New Method of using Paper Sections for the Determination of Cross Curves of Stability.

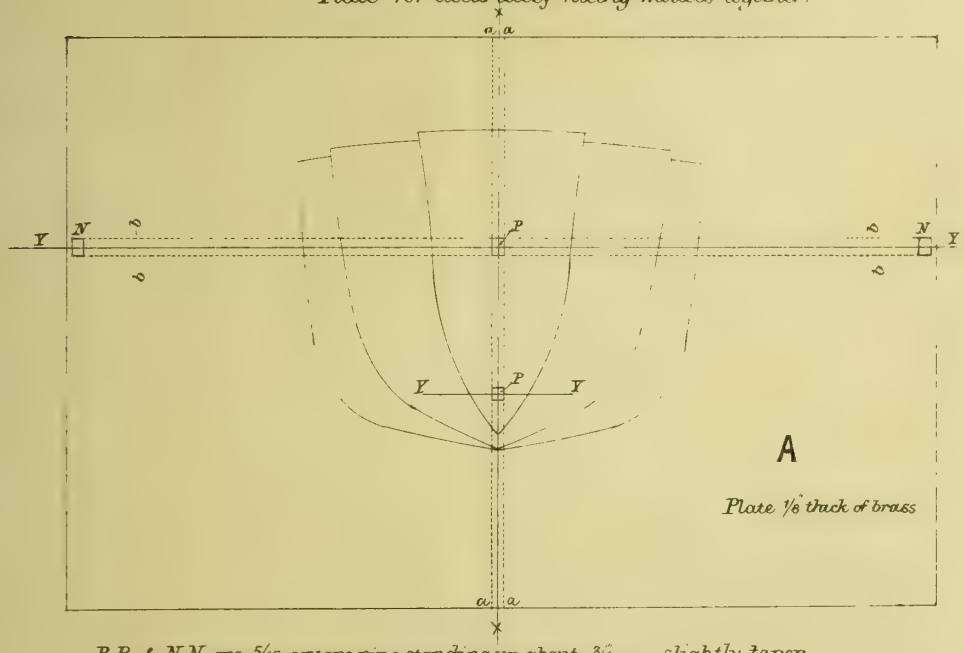


To Illustrate Mr. J. H. Heck's Paper on a New Method of using Paper Sections for the Determination of Cross Curves of Stability.

FIG. 2.

1/4 Size

Plate for accurately fixing models together.



P.P. & N.N. are 5/16 square pins standing up about 3/4 = slightly taper.

FIG. 3.

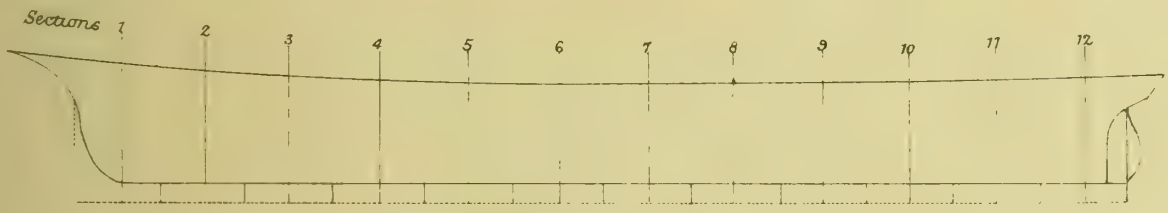
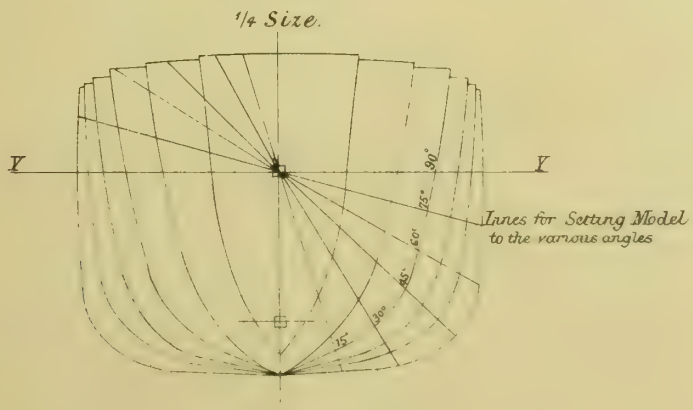


FIG. 4.

1/4 Size.



Model of Vessel 258 × 34 × 23.
Thickness of Model about 3/4 of an inch.

To Illustrate Mr. L. Benjamin's Paper on Stability Calculations by Means of the Planimeter.

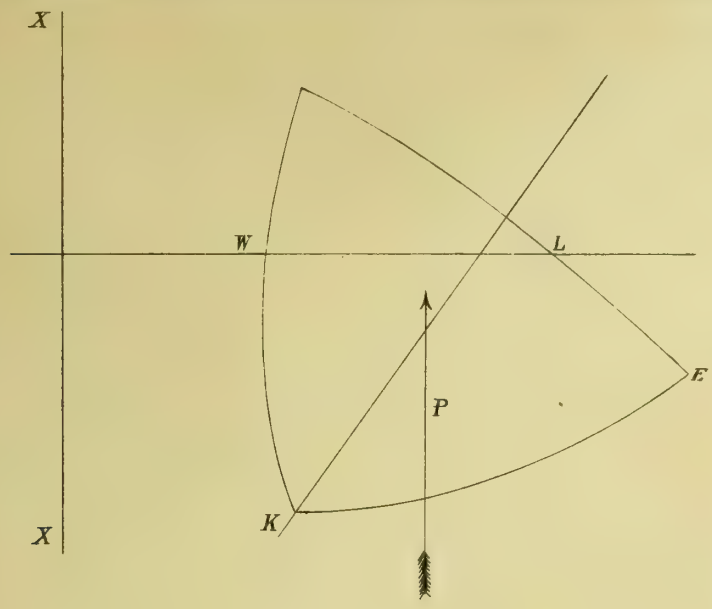


FIG. 1.

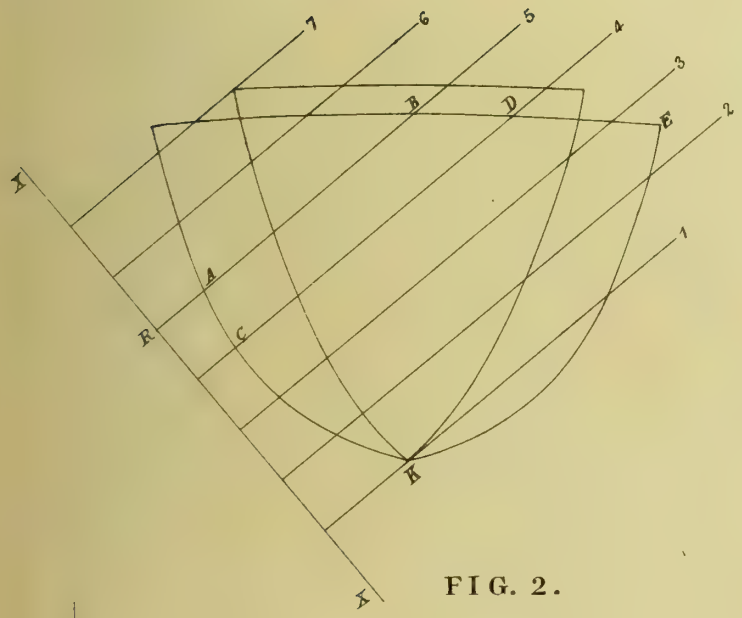


FIG. 2.

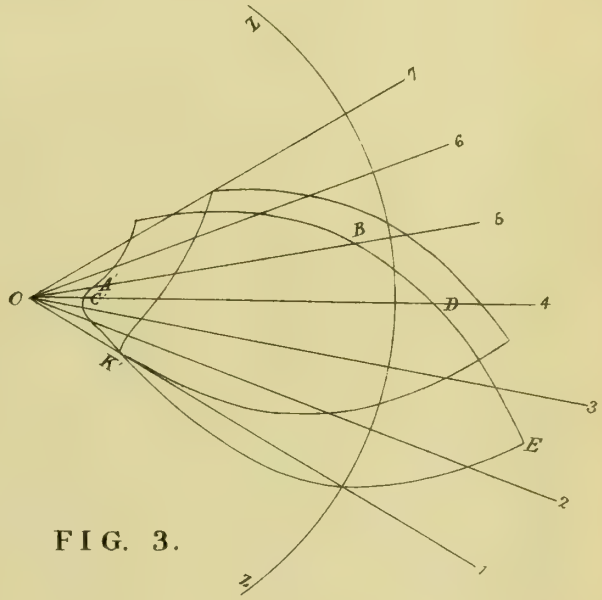


FIG. 3.

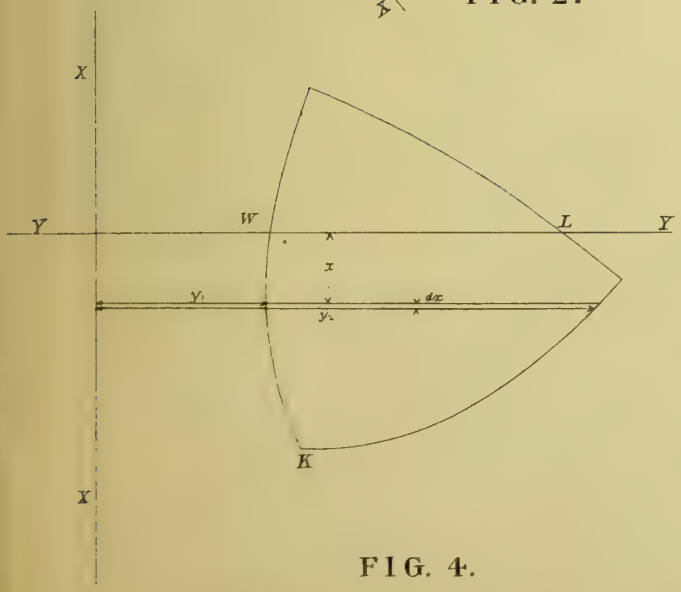


FIG. 4.

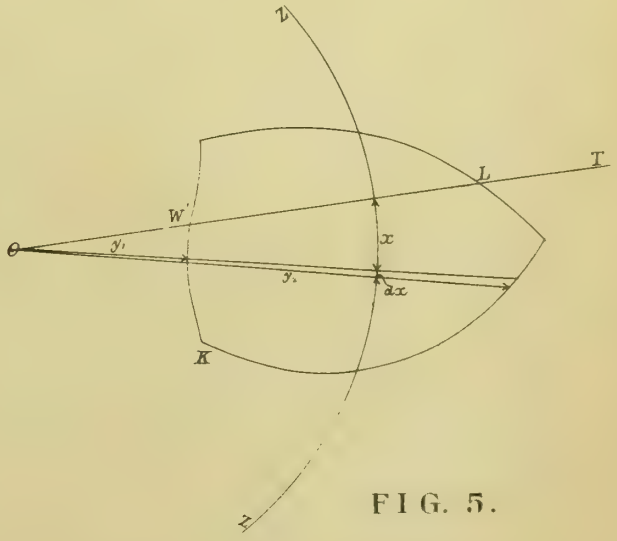
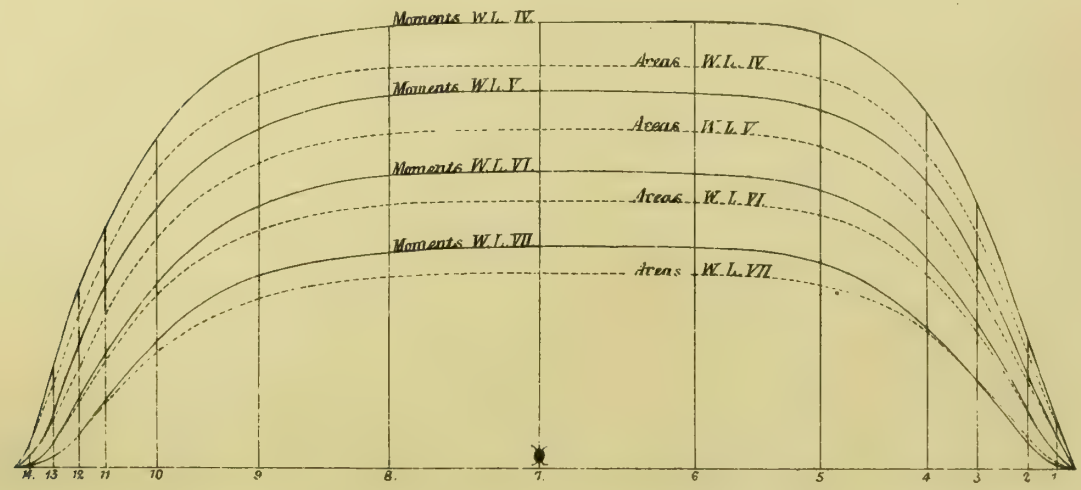


FIG. 5.

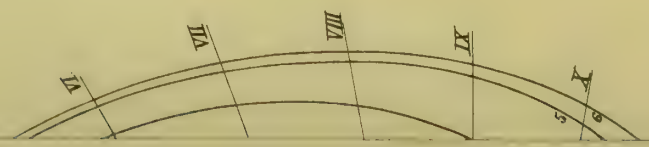
Plate XLIV.

Curves of Areas and Moments for 20° Inclination.

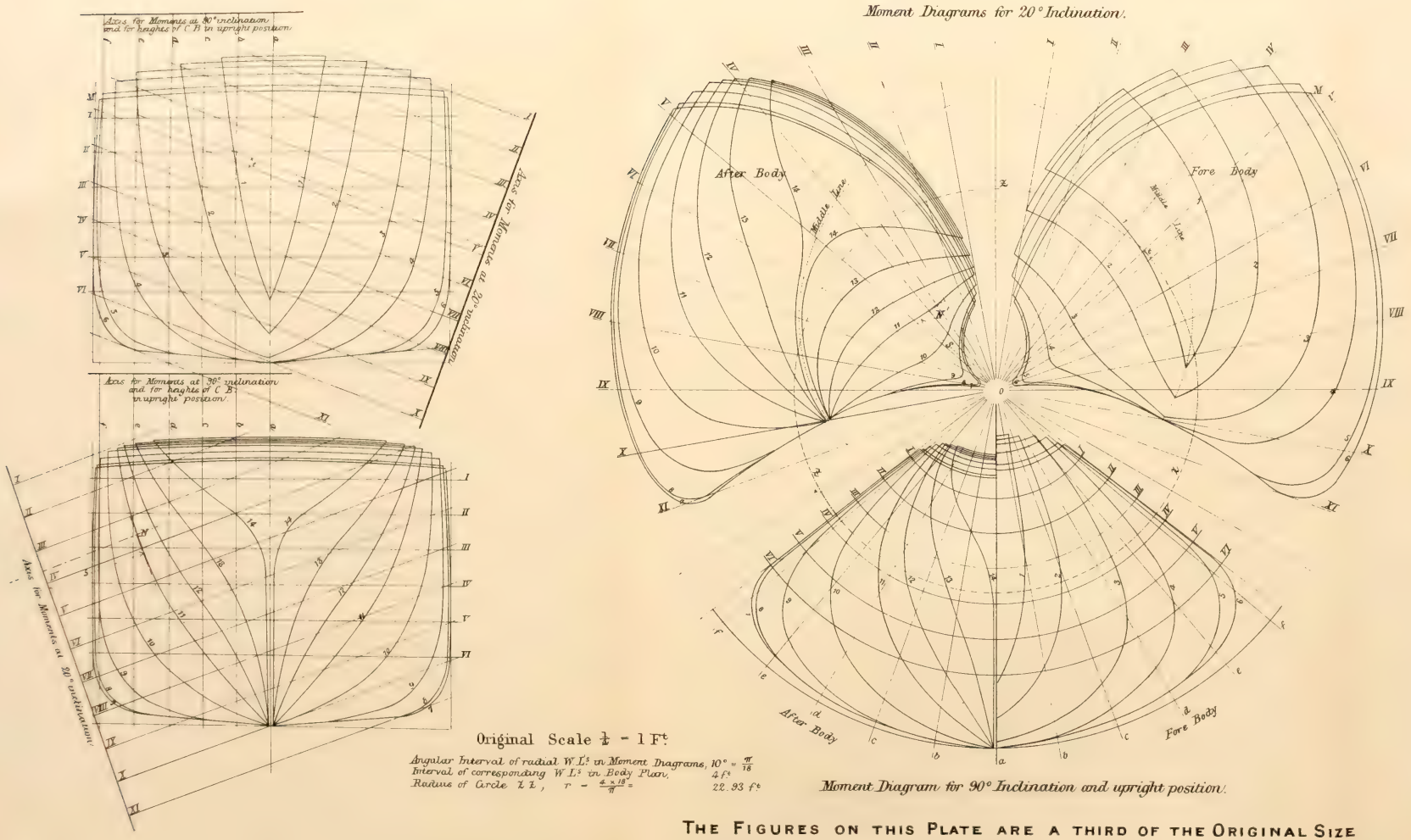


The ordinates in this Diagram represent the Planimeter Readings from the Body Plan and the Moment Diagram.
Original Scale of Ordinates: 0.1 in. = Plan Rdg. 100, or = 16 sq. ft. for the Curves of areas
and (16 × 22.93) sq. ft. × ft. for the Curves of Moments

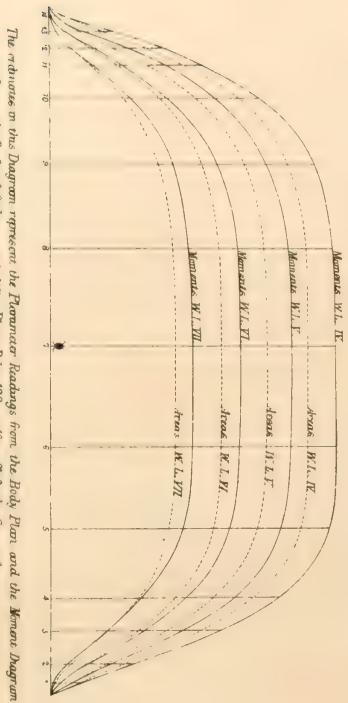
Original Longitudinal Scale 1 in. = 20 ft.
The Areas of these Curves are the Displacements (Plan Rdg 100 = 3200 cb. ft.)
and the Moments of the same (" " 100 = 73376 cb. ft. × ft.)



To Illustrate L. Benjamin's Paper on Stability Calculations by Means of the Planimeter.



THE FIGURES ON THIS PLATE ARE A THIRD OF THE ORIGINAL SIZE



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